FURTHER CONTRIBUTIONS TO THE SOLUTION OF THE PILTDOWN PROBLEM

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INTRODUCTION

We are now in a position to give an account of the full extent of the Piltdown hoax. The mandible has been shown by further anatomical and X-ray evidence to be almost certainly that of an immature orang-utan; that it is entirely Recent has been confirmed by a number of microchemical tests, as well as by the electron-microscope demonstration of organic (collagen) fibres; the black coating on the canine tooth, originally assumed to be an iron encrustation, is a paint (probably Vandyke brown); the so-called turbinal bone is shown by its texture not to be a turbinal bone at all, but thin fragments of probably non-human limb-bone; all the associated flint implements have been artificially iron-stained; the bone implement was shaped by a steel knife; the whole of the associated fauna must have been "planted," and it is concluded from radioactivity tests and fluorine analysis that some of the specimens are of foreign origin. The human skull fragments and some of the fossil animal bones are partly replaced by gypsum, the result of their treatment with iron sulphate to produce a colour matching that of the gravel. Not one of the Piltdown finds genuinely came from Piltdown. These latest investigations have demonstrated the methods now available which will not only make a successful repetition of a similar type of forgery virtually impossible in the future, but will be of further value in palaeontological research.

Gavin de Beer,
Director.

1. OUTLINE OF THE PILTDOWN PROBLEM

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THERE are three sites on or near Piltdown Common, Sussex, to which attention was originally drawn by Charles Dawson and where in the years 1908 to 1915 fossil and archaeological remains came to light. The first site is a gravel pit alongside the main drive in the grounds of Barkham Manor, about a hundred yards from the house. Here fossils and implements were found at intervals from 1908 to 1914. Smith Woodward was first informed of the skull (here referred to as Piltdown I) in a letter from Dawson dated 14th February, 1912. The gravel itself was noticed by Dawson as a likely source of Pliocene or Early Pleistocene fossils some years earlier, possibly in 1899 (Dawson, 1913 : 75). The second site is a field (its precise situation is not recorded) probably at Sheffield Park about two miles to the north-west of the first site. Here finds (Piltdown II) were reported by Dawson in 1915. The third site is at Barcombe Mills, four miles south-west of Piltdown ; cranial fragments said to have been obtained here were in Dawson's possession at the time of his death and were obtained for the British Museum by Smith Woodward. Neither the date of this discovery nor the exact spot has been recorded. Only at Barkham Manor were any systematic excavations carried out ; these were conducted by Smith Woodward and Dawson in 1912, 1913 and 1914, by Woodward alone in 1916—the year of Dawson's death—and spasmodically afterwards (Woodward, 1948). Nothing was found in the 1916 season, nor when gravel was dug at another spot nearer the farmyard some years later. The original site was re-excavated in 1950 under the auspices of the Nature Conservancy and a new trench dug to provide a permanent witness section of the Piltdown gravel (Toombs, 1952), but nothing human or animal came to light. The material from all three sites is considered in this report.

The bibliography on Piltdown is very large ; over 300 references were listed by W. & A. Quenstedt (1936), and a select list was given by Oakley (1952). The teeth and the cranial and mandibular fragments (Piltdown I and II) were described by Woodward (Dawson & Woodward, 1913, 1914 ; Woodward, 1917), and by Keith (1925), and the Barcombe Mills skull fragments by Ashley Montagu (1951). Accounts of the animal remains have been given by Woodward (Dawson & Woodward, 1914, 1915) and by Hopwood (1935). The flint implements were dealt with by Dawson in the first publications and by Woodward in *The Earliest Englishman* (1948). The unique bone implement was the subject of a special paper (Dawson & Woodward, 1915).

The circumstances and sequence of the finds, which have an important bearing on the controversies arising from Smith Woodward's interpretation and on the final invalidation of his conclusions by the disclosure of the fraudulent nature of the material, will be dealt with by one of us (J. S. W.) in a forthcoming book to be published by the Oxford University Press.

Smith Woodward accorded the finds at Barkham Manor full recognition as a new genus and species of the Hominidae—*Eoanthropus dawsoni*—of Early Pleistocene age, " defined by its ape-like mandibular symphysis, parallel molar-premolar series, and narrow lower molars which do not decrease in size backwards ; to which diagnostic characters may probably be added the steep frontal eminence and slight development of brow-ridges". Both the dating and the attribution of the remains to one individual were challenged at the first announcement of the discovery on 18th December, 1912. Newton and Keith favoured a Pliocene date (Dawson & Woodward, 1913), but the majority agreed with Dawson's and Woodward's Lower Pleistocene estimate, which remained undisputed until Edmunds, in 1925, made a new geological survey of the East Sussex region. In 1935 Hopwood placed the skull and jaw with the derived Villafranchian remains. The anatomical conclusion was disputed strongly by Waterston from the start (in Dawson & Woodward, 1913 : 150 ; Waterston, 1913) and by Miller (1915), Boule (1915), and others. To these authors the combination of a skull and mandible of such distinct types in a single individual seemed, on morphological grounds, highly improbable. They pointed out that the skull bones, if found by themselves, would certainly have been referred to the genus *Homo*, and the mandible, if found by itself, would as certainly have been accepted as that of an anthropoid ape. Thus two distinct forms were presumed to be present —fossil *Homo sapiens*, and a fossil ape named *Pan vetus* by Miller (1915) and *Boreopithecus dawsoni* by Friederichs (1932).

None the less, the evidence and arguments put forward by Woodward made a coherent and convincing case which was enormously strengthened by the finding of the canine in 1913 and Piltdown II in 1915. Keith restated and extended this case in 1915, giving his support to Woodward's thesis after careful weighing of the evidence. Not for many years could the evidence in any respect, anatomical, geological, archaeological or phyletic be shown with certainty to be untenable, though a number of serious criticisms were brought forward. On the available evidence the strength of the case for *E. dawsoni* may be judged by listing the arguments urged in favour of Woodward's interpretation:

1. The probable natural association of cranium with jaw was attested by their close physical proximity, especially so in a gravel formation—the mandible " within a yard " of where one piece of occiput had been found by Woodward in an undisturbed patch of gravel (Dawson, 1913), the canine in gravel " *in situ* excavated within a radius of 5 yards of the spot where the mandible was found " ; the nasal bones and " turbinal " within 2 or 3 ft. of the mandible.
2. The complementary nature of the fragments—mandible, canine and jawless cranium—in such close physical proximity pointed irresistibly to their natural association.
3. The state of mineralization, colour, and unrolled condition of the different pieces appeared very similar. The canine tooth, like the bony fragments, was apparently iron-stained.
4. There was positive anatomical evidence of the natural association between

lower jaw and cranium. In particular, the remarkable flat wear on the molars was a human and not an ape-like character, and functionally in entire accord with the human type of articulation of the glenoid cavity.

5. The canine in its wear also indicated a complete departure from the normal ape-like condition. The canine could not have overlapped in the normal simian fashion with the corresponding tooth in the opposing jaw since there is no attrition facet on either the proximal or distal aspect of the tooth.

6. The X-ray appearance of the roots of the molar tooth was much more reminiscent of the human than the ape condition (Keith, 1925).

7. Other arguments, of less weight than the foregoing, were (i) Pycraft's (1917) belief that the axis of alignment of the molar teeth in the jaw was much more like man than ape, (ii) Elliot Smith's view that the endocranial cast showed simian features and (iii) Woodward's (1932) inference that the order of eruption was human and not ape-like based on the much greater attrition suffered by the canine in comparison with that of the molar.

8. As a further refutation of the idea that the association of jaw and cranium was an accidental coincidence, there was the discovery of Piltdown II. The finding of another molar of the same type as those of Piltdown I, also associated with cranial fragments denoting a second individual not distinguishable from *Homo*, increased very greatly the probability of the natural association of mandible and brain-case.

9. The combination of hominid skull with ape-like jaw was not inadmissable on grounds of morphological incompatibility since there are many fossil instances of quite unexpected combinations of skeletal structures.

10. The existence of a creature like *E. dawsoni* was consistent with its reported geological age, as judged by associated fossils and the apparently " pre-Chellean " tools, for an ancestral or transitional form of this kind was to be expected in the Lower Pleistocene.

11. " Piltdown Man " was more simian than Heidelberg Man. Though morphologically very different from *Pithecanthropus* (then known only by skull cap, two doubtful molars and a disputed femur) it had as good a claim to represent the ancestor of *H. sapiens* since in brain size it was far more advanced than *Pithecanthropus*.

Woodward's interpretation was thus a close-knit set of arguments which took all the evidence into account. The alternative hypothesis that the discoveries represented two distinct creatures—fossil man and fossil ape—could not account for all the evidence without raising new complexities. To avoid the acceptance of Piltdown II as a second remarkable coincidence some doubted its authenticity. Hrdlicka (1922) suggested that the isolated molar must have come from the first site and that some mistake had been made—a suggestion denied by Woodward (1933). Weinert (1933) thought that the frontal bone of Piltdown II really belonged to Piltdown I. Weidenreich (1937) supposed that the isolated molar was human, so making Piltdown II a discovery of prehistoric *H. sapiens* only.

An anatomical argument against the association of the cranium with the mandible is that the bicondylar width of the mandible does not correspond to the distance between the mandibular fossae on the base of the skull, and therefore it is impossible to fit the mandible to the skull. But the symphysial region of the mandibular fragment is missing, and with no certain evidence of the position of the mid-line of the mandible there can be no certainty in estimating the bicondylar width.

However much evidence of the ape-like character of the mandible was brought forward (Miller, Ramström, Friederichs), the inference that the missing crucial condylar region would also be ape-like remained incapable of proof. With so much else ape-like, a variety of suggestions were made to account for the " un-ape-like " dental wear. Miller (1915) thought that similar flat wear might occasionally occur even in modern apes. The specimen which he adduced, however, was not only unusual but quite abnormal (Pycraft, 1917). Weidenreich (1937) drew attention to flat wear in the molars of a Pleistocene orang in Mme. Selenka's collection from Java but he only reproduced a photograph of this specimen and made no detailed comparison with the Piltdown molars. Both he and Miller left the peculiar wear on the canine unexplained. Marston (1952) has attempted to go further and has theorised as to the movements which might produce the Piltdown wear, supposing that the canine were an upper canine. But that such movements were ever made by a jaw with a structure, so far as it is known, and muscular attachments indistinguishable from that of modern apes remains completely hypothetical.

Nevertheless, certain of the criticisms of Woodward's conclusions cannot be disregarded. In particular, the " human " features said to exist in the mandible and teeth are few indeed (though they are crucial), whereas detailed study serves only to emphasise the astonishing similarity of the mandible to that of a modern orang or chimpanzee. Sicher's study (1937) deserves mention here, for, impressed by the completely non-human configuration of the dental foramen and its relation to the mandibular canal, Sicher questioned the association of the jaw and cranium. Keith (1925) himself did much to throw doubt on certain alleged simian features of the braincase and endocranial cast brought forward by Elliot Smith. Symington (1915) severely criticized the latter's conclusions, and could find no convincing evidence of any precocious or peculiar development in the brain of *Eoanthropus*. Lyne (1916) drew attention to the extraordinary contradiction between the apparent immaturity of the canine and its excessive wear, but his explanation that the tooth might be a milk canine had little to support it and his important observations were disregarded. Miller (1918) and Marston (1952) threw doubt on Pycraft's belief in the " near-human " alignment of the molars in the jaw. Doubts had early been expressed on the workmanship of the bone implement (Reginald Smith, in discussion of Dawson & Woodward, 1915 ; Breuil, 1938) ; these were renewed by Oakley in 1949.

The interpretations of Woodward and his critics were beset with new difficulties when fluorine tests (Oakley & Hoskins, 1950) showed that *E. dawsoni* could not be accepted as a Late Pliocene derivative, but was apparently contemporary with the gravel. Combined with Edmunds' conclusion of 1926, this implied the dating of the remains to the last interglacial period, i.e. the early part of the Upper Pleistocene. These difficulties were further enhanced from about 1925 onwards by many new discoveries of *Pithecanthropus* (both in Java and China), of the Australopithecinae and of fossil apes (particularly in E. Africa.)

By 1950 every possible opinion of " Piltdown Man's " status had been discussed. Weidenreich (1947) had decided to dismiss the " chimaera " altogether ; Friederichs (1932), Montagu (1951), Marston (1952) and others believed that the remains represented two distinct fossil creatures ; some (Howells, 1947 ; Leakey, 1953) felt that the situation was so confused that no definite decision could be made ; others, that the matter should be left in " suspense account " (Le Gros Clark, 1949) in the hope that more material might be found ; and there were some for whom " *Eoanthropus dawsoni* " continued to figure unquestioned as a species or genus of the Hominidae. Finally, Weinert (1953) thought that the jaw, if properly reconstructed, would turn out to be hominid and by no means ape-like.

The hypothesis of a fake or hoax

In the new situation created by the revised dating the only two conceivable " natural " explanations both seemed entirely inadequate on evolutionary grounds and the many puzzling anatomical features remained unresolved. How else could all the apparent facts be explained ?

The possibility had to be faced that the Piltdown finds were a hoax—that the mandible was indeed that of an ape, but of a modern ape so treated by mutilation of the fragment, abrasion of the teeth and staining as to appear a genuine fossil. Not only could this hypothesis at once explain the circumstances of the finds and the sequence of discoveries, it could also be entertained on the following grounds:

(1) That the only morphological feature in the mandible which could not be said to be ape-like was the wear on the molars and it seemed surprising that this should be the only undoubted feature to link the cranium and mandible.

(2) That filing down of chimpanzee and orang molars was found to produce an appearance similar to that of the Piltdown molars.

(3) That artificial abrasion would explain the baffling and unique wear of the canine.

(4) That the very parts of the mandible which one would expect a faker to remove were, in fact, broken off.

(5) That Oakley (in 1949) found the dentine under the thin, dark " ferruginous" layer to be "most unexpectedly—pure white". (Oakley & Hoskins, 1950:381).

(6) That the 1949 fluorine analysis had left the antiquity of the mandible quite indeterminate. It had, in fact, " failed to differentiate *Eoanthropus* from Holocene bones". (Oakley, 1951 : 50).

(7) That an element of doubt already surrounded the bone implement.

An exhaustive re-examination of all the Piltdown finds has completely confirmed the hypothesis of a hoax, and experimental work has shown that all the features of the Piltdown teeth and jawbone can be reproduced artificially. The main results have already been published (Weiner, Oakley & Le Gros Clark, 1953). The present series of reports gives the evidence in greater detail and covers a wider field.

2. AN ANATOMICAL STUDY OF THE PILTDOWN TEETH AND THE SO-CALLED TURBINAL BONE

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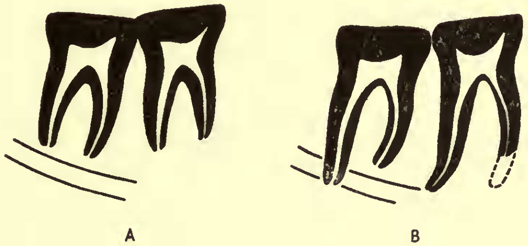
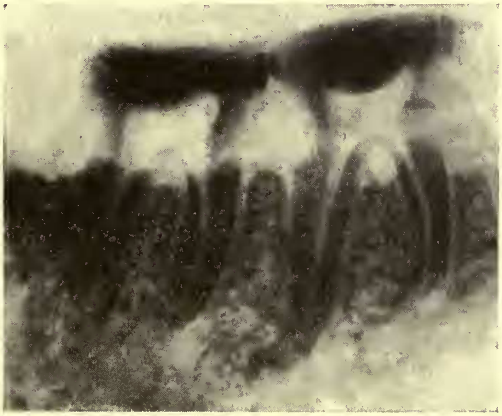
(I) THE ANATOMICAL DETAILS OF THE PILTDOWN TEETH

The teeth from Piltdown are the first and second right lower molars in the mandibular fragment, an isolated canine tooth, and an isolated left lower molar tooth. The last was reported to have been found in a heap of stones raked off a ploughed field about two miles from the original Piltdown site. Considered by themselves, it seems certain that the teeth would have been attributed to an anthropoid ape (quite similar to a chimpanzee or an orang) except for two main features : (1) the extremely flat wear of the molar teeth in the mandible, which is not normally to be found in pongid teeth at an equivalent stage of attrition, but which closely approximates to the type of wear commonly found in hominid molars ; and (2) the quite unusual type of wear on the canine which, so far as we are aware, is not paralleled in the canines of any of the known genera of anthropoid apes, recent or extinct. The suggestion that these aberrant features might be the result of artificial abrasion at once offered a plausible explanation of their seemingly anomalous character. Indeed, it may well be asked why such a suggestion had not been seriously considered until quite recently. There are no doubt several reasons for this. In the first place, the mandibular fragment and the canine tooth were reported to have been found by experienced palaeontologists during their excavations at Piltdown, and the occurrence *in situ* has thus always been accepted without question. Secondly, the faking, obvious though it now appears, had been accomplished with extraordinary skill ; and, lastly, the statement that the worn surface of the canine shows an exposure of secondary dentine would almost certainly have distracted attention from a possible consideration of faking by artificial abrasion. Secondary dentine is deposited as a reaction to prolonged natural wear and its presence in the canine would thus presuppose that the excessive wear of this tooth was indeed natural. In fact, a re-examination of the canine has shown that there is no evidence of the deposition of secondary dentine.

Two other relevant features have been held by some authorities to distinguish the Piltdown molars of the mandible from those of anthropoid apes. One is their hypsodont character. But comparative study has shown that, while a similar degree of hypsodonty is very unusual (if, indeed, it does occur) in chimpanzees and gorillas, it is not uncommon in the orang. The other feature is the relative shortness of the roots of the molar teeth as they appeared to be displayed in the original radiograph of the Piltdown molars published in a paper by Underwood (1913) and subsequently copied in publications by other authors (e.g. Keith, 1915; Lyne, 1916). But new radiographs taken recently show quite clearly that the roots are in fact markedly longer than they have been portrayed, and are thus entirely simian in appearance. This seems to us to be an important point which needs to be emphasized. The original radiographs lacked sufficient definition to outline the roots distinctly: from the recently taken radiograph the outlines of the molars have been reproduced for comparison with those made from appearances shown in the original radiograph (Text-figs. 1, 2). It will be observed that the lower end of the anterior root of $\overline{\mathrm{M1}}$



Text-fig. 1. A. Outline drawing of the molar teeth in the Piltdown mandible showing the roots as they had been interpreted on the basis of the original radiograph published in 1913. B. A similar drawing made from a recent radiograph showing the actual form and extent of the roots. The anterior root of $\overline{\mathrm{M1}}$ has been broken off, and its probable extent is indicated by a broken line. In both figures the position of the mandibular canal is shown. Natural size.

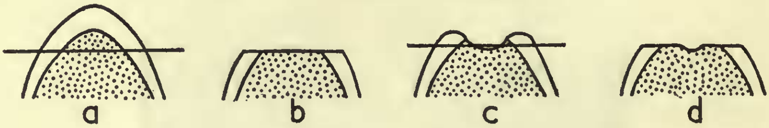


Text-fig. 2. Radiograph of the two molar teeth in the Piltdown mandible showing the form and extent of their roots. Note the apparently accurate apposition of the crowns of the teeth at their contact facets. Twice natural size. [*X-ray by P. E. Purves.*]

has been broken off (presumably it has been involved in the fracture of the mandible at this level). Its total length can therefore not be precisely estimated, but there is an indication of the lower end of the socket which suggests that originally the apex of the root curved downwards and backwards for some distance. The posterior root of $M\overline{1}$ is long and is deflected backwards at its lower extremity. The radiograph of the mandible shows that it actually reaches the upper border of the mandibular canal. The anterior root of $M\overline{2}$ is well defined and was correctly displayed in the original radiograph. Compared with the posterior root of $M\overline{1}$, the rounded and blunt apex of this root and the relative width of the apical canal suggest that the root had perhaps not completed its full development. The posterior root of $M\overline{2}$ is considerably longer than the anterior root, extending downwards to the level of the lower border of the mandibular canal. This relationship is of some significance, for the " hominid " appearance in the original radiograph showing the roots of both the first and second molars apparently falling well short of the canal certainly misled some authorities. Like the anterior root, the apex of the posterior root of $M\overline{2}$ is bluntly rounded and the apical canal relatively wide.

The problem having been posed—is the unusual type of wear of the Piltdown molar teeth the result of natural attrition during life or of artificial abrasion after death ?—consideration was given to those details which on close inspection might be expected to differentiate the one from the other. A critical study of the teeth at once revealed certain features which had either escaped notice previously, or the possible significance of which had not been realized. Indeed, it was because these features appeared to lend such strong support to the hypothesis of artificial abrasion that it was decided to re-examine all the Piltdown material for further evidence of faking.

The flatness of the molar teeth is astonishingly even over almost the entire extent of the occlusal surface, as though, indeed, the latter had been planed down by some rapidly acting shearing force. A considerable area of dentine (about 4 mm. in its greatest diameter) has been exposed on the antero-internal cusps of both teeth, and not only are these areas quite flat, they are also flush with the surrounding enamel (Text-fig. 3, *a*, *b*). But in natural attrition, whether in hominids or pongids, areas



Text-fig. 3. Diagram illustrating the peculiar type of abrasion on the cusps of the Piltdown molar teeth. In (*a*) is shown a schematic section through an unworn cusp. If this were subjected to artificial abrasion in the plane indicated, the appearance shown in (*b*) would be produced, i.e. a flat area of exposed dentine (stippled) flush with the surrounding enamel; such an appearance is seen on the antero-internal cusps of the Piltdown molars. In (*c*) is shown a schematic section through a cusp partially worn by natural attrition, illustrating the concavity of the dentine depressed below the surrounding enamel. Artificial abrasion in the plane indicated would produce the appearance shown in (*d*), i.e. a depressed " dimple " in the centre of a flat area of dentine flush with the surrounding enamel; such an appearance is seen on the antero-external cusps of the Piltdown molars.

of dentine exposed to this degree form shallow concavities, because the less hard dentine wears away more rapidly than the surrounding and harder enamel. The possibility that the appearance of the occlusal surfaces of the Piltdown molar teeth might be the result of an unusual type of natural attrition, which had proceeded so rapidly that there was insufficient time for the exposed dentine to be hollowed out below the level of the surrounding enamel, does not seem an acceptable explanation. In the first place we have not been able to find, in an examination of 137 ape jaws and 200 human jaws, a parallel condition in areas of dentine of similar extent exposed by natural attrition. Secondly, the small punctate exposures of dentine on the external cusps of the Piltdown molars are in fact already depressed below the surrounding enamel, presumably as the result of natural wear (and thus indicating that the latter was originally of the normal type). Moreover, on the antero-external cusp of both molars the punctate exposure of dentine is surrounded by a small and perfectly flat area of dentine which, it appears, must have been exposed (like the areas of dentine on the antero-internal cusps) by artificial abrasion (Text-fig. 3, *c*, *d*). These flat areas of dentine are stained a brown colour and are sharply defined by a thin outline of deeper staining. We have been able to produce outlines of somewhat similar appearance in modern teeth which have been filed down and artificially iron stained, and it seems probable that the outline of deeper staining may be due to the relatively rich amount of organic substance at the dentino-enamel junction, where there is a greater proportion of interprismatic substance to enamel-rods (Noyes, 1948), and also to the considerable degree of branching and interlacing of dentinal tubules at the surface of the dentine.

Another curious feature of the molars of the Piltdown mandible is that the dentine on both $M\overline{1}$ and $M\overline{2}$ is much more extensively exposed on the antero-internal than the antero-external cusps. But this is the reverse of natural wear, in which the outer cusps of the lower molars are normally worn down more rapidly in the earlier stages of attrition. Out of 200 human jaws there were only 4 in which (at an approximately equivalent stage of wear) the dentine of a lower molar was exposed to an approximately equal extent on the outer and inner cusps; in one other the area of exposed dentine on the inner cusp was rather more extensive (though by no means to the degree shown in the Piltdown teeth). Thus with normal occlusion it must be at least very exceptional to find human teeth in which the wear on the antero-internal cusps is so much greater than on the antero-external cusps of $M\overline{1}$ and $M\overline{2}$ as to be comparable with the Piltdown molars. In ape molars also, so far as we have been able to determine from the evidence of 137 jaws of the modern large anthropoid apes, as well as 38 specimens representing 9 different genera of fossil apes, the wear is normally greater on the outer cusps. In no case did we find a lower molar tooth showing the reversed condition seen in the Piltdown molars (though in one female gorilla there were small punctate exposures of approximately equal extent on the antero-internal and antero-external cusps of $M\overline{1}$). This evidence makes it difficult to explain the relative wear of the outer and inner cusps of the Piltdown teeth except by the hypothesis of artificial abrasion.

This inference is further supported by the sharp edges with no bevelling which bound the flat occlusal surfaces of the molars at their margins. The absence of bevelling at the external margin seems particularly significant, for normally this margin shows distinct bevelling caused by the overlap in occlusion of the external cusps of the upper molars. In only 10 out of 200 human jaws was the lateral margin of the lower molar teeth found to be as sharp-cut as those of the Piltdown mandible (but these exceptions did not show the other unusual features of the supposedly fossil specimens). The sharpness of the edge in the Piltdown molars is consistent with the postulate of artificial abrasion, and a similar appearance is to be seen on the talonid basin of the second molar. This depression, which is still relatively unworn, is also separated from the quite plane occlusal surface of the crown by a sharp unbevelled edge. We have not been able to find a similar feature in our series of ape and human jaws in which the lower molars have been exposed to natural attrition. For, in normal occlusion, the protocone of the upper molar fits into the talonid basin of the opposing lower molar and in normal wear produces a sloping rounded edge at the margin of the depression. On the other hand, the sharp unbevelled edge seen in the Piltdown molar would be expected to result from an attempt to produce a flattened surface by artificially planing down a more or less unworn tooth. Examination of the occlusal surfaces of the two molars under a binocular microscope provides further evidence, for here and there the enamel and dentine are scored with extremely fine scratches, sometimes disposed in a criss-cross pattern. Such scratches, which are not apparent to the same degree over the enamel on the sides of the crowns, strongly suggest the application of an abrasive of some sort.

A further point to notice in the first and second molars of the Piltdown jaw is that they both show almost exactly the same degree of wear. But normally the wear of the first molar is distinctly more marked, since it has been longer in use. Exceptional cases, however, do occur in human lower molars in which the wear of the two teeth is approximately equal, and it may happen that the second molar is the more severely worn as the result of some defect in the upper dentition. In our series of 137 ape jaws, we have only found three instances (chimpanzees) in which the first and second molar teeth are worn to about the same degree. It appears, therefore, that the condition in the Piltdown molars is at least very unusual.

One more suggestive feature is to be seen in the mandibular molars—their occlusal planes are not quite congruous, i.e. they do not fit together to form a uniform contour. The posterior margin of $M\overline{1}$ at its inner end projects about 2 mm. above the adjacent anterior margin of $M\overline{2}$, and the occlusal plane of $M\overline{1}$ is set at a slight angle to that of $M\overline{2}$. On the other hand, the outer end of the posterior margin of $M\overline{1}$ is level with the adjacent anterior margin of $M\overline{2}$. The possibility that this might be due to a post-mortem displacement of $M\overline{1}$, the occlusal surface of the latter having as a result been rotated slightly outwards about the axis of its outer margin, is negatived by two observations: (1) the radiograph of the molar teeth in lateral view shows that their roots fit accurately into their sockets, and (2) there is no sign of a contact facet on the exposed posterior surface of $M\overline{1}$ (which might be expected if this tooth had been displaced upwards relative to $M\overline{2}$). Radiographs of the teeth in lateral view also appear to show the contact facets between them in accurate apposition (see Text-fig. 2). It is true that the two molars are not in exact symmetrical alignment, but this is a common feature in an immature mandible in which the eruption of the permanent dentition is in process of final completion and in which the second molar has not completely rotated to its final position in the alveolar border. On the other hand, a recent radiograph of the teeth from their occlusal aspect shows a slight gap between the anterior root of $M\overline{1}$ and the inner wall of the socket, suggesting a slight displacement outwards of the tooth. Even so, it still would not be possible with the slight readjustment which would be necessary to correct it, to bring the occlusal planes of the two molars into precise conformity, the more so because the posterior margin of $M\overline{1}$ is slightly concave in contrast to the quite straight anterior margin of $M\overline{2}$. This evidence of the lack of conformity between the occlusal plane of the two teeth adds further support to the hypothesis of artificial abrasion, for it suggests that the process of paring down has been applied separately to each tooth. Taken by itself, this is not perhaps entirely conclusive, for as the result of mal-occlusion resulting from some defect of the upper dentition incongruities may occasionally occur in teeth exposed to natural attrition.

The enamel bordering the dentine exposure on the antero-internal cusps of $M\overline{1}$ and $M\overline{2}$ has been cracked and chipped, and on $M\overline{2}$ a small flake has evidently become detached and been replaced in position with some adhesive. We have found in our experimental grinding of molar teeth that this type of cracking and chipping of the enamel is very liable to occur, though it can be minimized by embedding the teeth in plaster of Paris, and it is therefore of particular interest to find that the Piltdown molars are similarly affected.

The radiograph demonstrates the presence of a small lobulated odontoma in the pulp cavity of $M\overline{1}$, an unusual feature which, however, has no particular relevance to the Piltdown problem.

The isolated lower left molar (probably $M\overline{1}$) reported to have been found in a heap of stones raked off a field two miles from the site of the Piltdown excavations is so closely similar in dimensions and shape to the mandibular molars that it probably belonged originally to the same individual. However, it does not show the same degree of flat wear and, no doubt for this reason, some authorities have refused to associate it with the Piltdown jaw. But if the wear of the molars has been artificially produced, such an objection no longer remains valid. An examination of this isolated tooth with a binocular microscope shows that the enamel on the occlusal surface of the crown is scored with fine scratches, similar to, but rather coarser than, those already noted on the mandibular molars.

The evidence of the isolated canine tooth found in 1913 is consonant with that of the molars. The radiological evidence that this tooth had not yet completed its full development appears to be sound. The pulp cavity is widely open at the apex of the root, and even if this is assumed to be the result of post-mortem damage, it would not account for the relatively large size of the cavity as a whole. But, if the tooth is immature, it is difficult to explain the severe degree of attrition of the lingual surface of the crown unless it has been artificially produced.[1] For the entire thickness

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[1] The large size of the pulp cavity had been noticed many years ago by Lyne (1916), but he sought to explain the combination of this feature with the severe wear on the assumption that the tooth is a deciduous canine of unusual size.

of the enamel has been removed over the entire extent of the lingual surface, from the anterior to the posterior border of the crown. Over a small area just above the middle of the worn surface the dentinal wall of the pulp cavity has been reduced to a thickness of less than 1 mm., and at one point the pulp cavity has actually been penetrated. At that point a rather curious feature is seen in the radiograph, for it appears that the opening into the pulp cavity has been plugged with some plastic material which is not itself radio-opaque (but which contains some fine dust-like particles which are radio-opaque).[1] Further, the radiographs show no evidence of the deposition of secondary dentine, with a narrowing of the pulp cavity, such as might be expected if the severe attrition of its lingual surface had been naturally produced. It is now clear that, in the original descriptions of the tooth, the material used for plugging the opening into the pulp cavity was mistaken for secondary dentine. Apart from the severity of the wear of the canine, the pattern of attrition is quite unlike that found in any ape (recent or extinct), whether the canine belongs to the upper or lower dentition. It has, indeed, been argued that such a type of wear might be theoretically possible in an ape's jaw, given certain unusual occlusal relationships and movements of the jaw, but (apart from the questionable validity of these arguments) the fact is that it has never been demonstrated to occur in any known pongid or hominid. The contour of the worn surface is in fact peculiar, for while it is evenly concave in a vertical direction it is almost flat from before backwards and it is not accompanied by an attrition facet on the anterior or posterior margin of the tooth.[2] It is exceedingly difficult to imagine an occlusal relationship which could have produced such a contour by natural wear, and it is little wonder that in the early discussions on the Piltdown " fossil " there was some controversy whether the attrition was caused by contact with the opposing canine or lateral incisor tooth. On the other hand, the contour of the worn surface is quite consistent with the surmise that the latter was abraded by artificial means.

It may be argued that at least some of the details of the Piltdown teeth which have been described, when considered separately, are inadequate by themselves to confirm the thesis that the teeth have been deliberately fabricated to simulate fossil specimens. But when they are taken together we are forced to the conclusion that they could not possibly have been produced other than artificially.

In attempting to decide whether the jaw and teeth are those of an orang or a chimpanzee, one must remember that the artificial abrasion has removed or otherwise damaged the finer details of dental morphology which distinguish these two genera. Even so, it is possible to say that they are almost certainly those of an orang. Thus, the hypsodont character of the molars and the size and shape of their pulp cavities are quite similar to those of orang teeth (Text-fig. 4), but differ markedly from those of chimpanzees which we have examined. Again, the pattern of the

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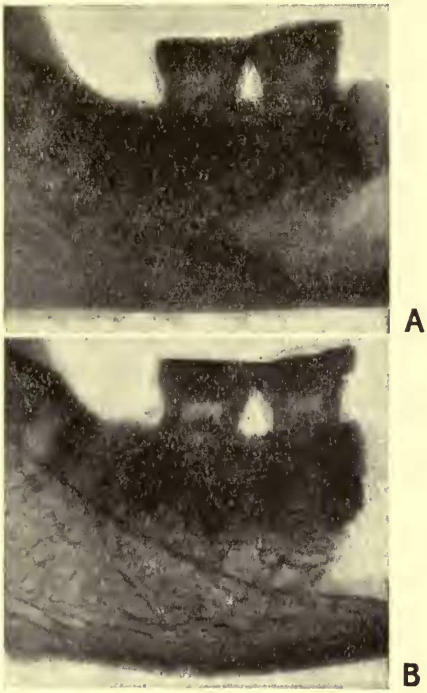
[1] The penetration of the pulp cavity was not evident in the radiographs of the canine reproduced in the original communication of Dawson & Woodward (1914), for the reason that they did not happen to have been taken in just the appropriate plane.

[2] When the canine tooth was picked out of a heap of gravel in 1913, it was found accurately to resemble in shape the plaster model of the canine which had already been reconstructed to fit the Piltdown mandible. Commenting on the discovery in a postscript dated 16th September, 1913, Underwood (1913) wrote " The tooth is absolutely as modelled at the British Museum."

dentine exposure corresponds very closely to that produced in our experimental abrasion of orang molars, and the numerous small fissures and pits in the central part of the occlusal surface are clearly the residual traces of crenulations of some complexity. Indeed, in one orang jaw in which we abraded the first and second molar teeth, they were found to duplicate the appearance of the Piltdown molars to a remarkable degree, not only in the extent and the contour patterns of the dentine exposures on the several cusps, in the size, depth and abrupt margins of the central basin, and in showing an approximately similar residuum of crenulations, but also in the general proportions of the crowns as a whole (including their height as measured above the enamel margin). See Pl. 27.



TEXT-FIG. 4. Radiographs of (A) the Piltdown molar teeth, compared with (B) those of the female orang mandible shown in Pl. 27, fig. 2. The orang is evidently more fully mature than the fossil specimen, as shown by the slightly smaller size of the pulp cavities and narrower root canals of the molars, and by the fact that the mandible as a whole is a little more robust. (For a radiograph of orang molars showing pulp cavities of practically identical size and shape with those of the Piltdown teeth, see Weidenreich, 1937, fig. 320). [*X-rays by P. E. Purves* (A) and *G. M. Ardran* (B).]

(II) THE " TURBINAL BONE "

In the supplementary note on the discoveries at Piltdown (Dawson & Woodward, 1914), Dawson stated " I saw two human nasal bones lying together with the remains of a turbinated bone beneath them *in situ*. The turbinal, however, was in such bad condition that it fell apart on being touched, and had to be recovered in fragments by the sieve; but it has been pieced together satisfactorily". The only other reference to this find was made by Woodward in the same communication, and is limited to the following statement: "The remains of a turbinal found beneath the nasal bones are too much crushed and too fragmentary for description; but it may be noted that the spongy bone is unusually thick, and has split longitudinally into a series of long and narrow strips." No reason was given for identifying the fragments as those of a turbinal (it is clear that a maxillo-turbinal bone is meant to be indicated by this term), except presumably by implication its proximity "*in situ*" to the nasal bones. Moreover, contrary to Dawson's statement, the tiny fragments (eight in number) are separate and it is not possible to fit them together to form a complete bony element.

From an examination of these fragments it is clear that, whatever their true identification may be, they are certainly not those of a turbinal bone. They show none of the characteristic features of the maxillo-turbinal (such as its extreme thinness or its pitted and cellular texture). On the contrary, the fragments are relatively thick and they show a longitudinally grained texture which indicates that they are composed of Haversian systems arranged in parallel formation. Presumably, therefore, they are derived from the shaft of a limb bone (probably of some small animal), but their precise identification is indeterminate.

3. THE PILTDOWN "IMPLEMENTS"

By K. P. OAKLEY

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(I) THE FLINT " IMPLEMENTS "

Dawson recorded that the Piltdown gravel is composed of Wealden ironstone pebbles, mixed to the extent of about one-sixth of the mass with angular brown flints, a large proportion of which are tabular in form with fractured edges, frequently conforming to the so-called eoliths of the Plateau Gravels. He was duly cautious with regard to eoliths. " Whether natural or artificial, the fractures appear to have been largely governed by the prismatic structure of the flint " (later he introduced the term starch-fracture to describe breakage of this type). He pointed out that the rolled examples had a deep iron-stained patina, whereas the unrolled ones were less deeply stained and patinated. He said that there also occurred in the Piltdown gravel " certain brilliantly coloured iron-red flints,, presumably more highly oxidised than the prevailing flints, which were of a brown colour." He continued : "Among the flints we found several undoubted flint-implements, their workmanship being similar to that of the Chellean or pre-Chellean stage ; but in the majority . . . the work appears chiefly on one face of the implements."

Only four of these " Palaeolithic implements " were figured by Woodward and Dawson in their joint papers, as follows :

E.605. (Pl. 28, fig. 3B). Side-blow flake of pointed foliate form, 9 cm. × 5 cm., with maximum thickness 2·5 cm.

The whole surface is patinated and stained yellowish-brown, the edges are dulled. See Dawson & Woodward 1913, pl. XVI, 1, 1*a*, *b*; Sollas 1924, fig. 81; Woodward 1948 : 40, fig. 9*a*.

According to some unpublished notes, Woodward found this " best formed tool " loose in one of the heaps of gravel rubbish at the main site.

E.606. (Pl. 28, fig. 3C). Triangular bifaced point, with area of smooth brownish stained cortex at the butt ; 8 cm × 6 cm., with maximum thickness of 2·5 cm. The flaked surfaces are patinated with a superficial pale yellowish brown stain, the edges are dulled. See Dawson & Woodward, 1913, pl. XVI, 2, 2*a* ; Woodward 1948 : 40, fig. 8*a*.

This " palaeolithic tool " is recorded by Dawson (in Dawson & Woodward 1913 : 122, footnote 1) as having been found *in situ* by Father Teilhard de Chardin, in the loamy stratum of the Piltdown gravel (see p. 275).

E.607. (Pl. 28, fig. 3A). Massive flake of squarish form, 14 cm. × 13 cm., with maximum thickness of 5 cm. The flaked surfaces are patinated and stained bright orange, the edges are dulled. See Dawson & Woodward, 1913, pl. XVI, 3, 3*a*, *b*; Breuil, 1949, fig. 4. According to unpublished notes by Woodward this specimen was found by Dawson on a heap of gravel rubbish at the main site.

E.613. Heavily rolled, oval end-struck flake, 6·5 cm. × 5 cm., 1·5 cm. thick, of dark greyish flint with thin buff patina, the surface of which has a patchy, dark red ferruginous stain. See Dawson & Woodward, 1914: 84, pl. XIV, 1*a–c*; Breuil, 1949: 344, fig. 1; Oakley 1949, fig. 30.

This is the only artifact which was recorded as having been found *in situ* in the dark brown basal gravel.

The first three specimens have a number of features in common:

(1) Although for the most part fractured by human agency, the form of each appears rather more accidental than intentional; (2) each is an atypical artifact, not referable with certainty to any particular culture; (3) each is in flint of a quality not found as unworked pieces in the Piltdown gravel; (4) the patina of each artifact has a ferruginous staining which is unusual in its bright colour (varying from orange to light yellowish brown) and in its patchy, rather stippled appearance (Pl. 28, fig. 4); (5) each specimen shows evidence of some heavy localised battering (Pl. 28, fig. 3 A–C) on the original exterior or cortex of the flint prior to its being flaked from the parent block.

The peculiar staining and the lithology of these three specimens are exactly matched by a core which was discovered recently in a cabinet formerly belonging to the late Mr. Harry Morris of Lewes. This specimen (Pl. 28, fig. 3D) is now preserved in the British Museum (Natural History). In an accompanying note, Morris drew attention to its similarity to the worked flints from Piltdown, and claimed that to his own knowledge this flint had been artificially stained. The patina itself appears to be natural, so the flaking is prehistoric, but judging from the style of work it is probably Mesolithic or Neolithic rather than Palaeolithic.

When dilute hydrochloric acid is applied to the surfaces of the Piltdown " palaeoliths " and Morris's flint the orange or yellowish brown stain is dissolved and can be wiped off, leaving a pale yellowish or greyish white surface of patina. In marked contrast, it has been found that the brown patina of the " eoliths " and of other flints collected from the Piltdown gravel, is unaffected by hydrochloric acid. (Pl. 28, figs. 5, 6).

Experiments carried out in collaboration with Dr. A. A. Moss in the laboratory of the Mineral Department of the British Museum have shown that the colour of the orange and yellowish or reddish-brown stained flints from Piltdown can be reproduced by dipping white-patinated flints in a solution of ferric chloride of various strengths and then treating the wet stain in ammonia fumes to produce ferric oxide.

The surface stains of a number of flints from Piltdown, including the figured ones, were first tested for us by Dr. E. T. Hall in the Clarendon Laboratory, Oxford, using his X-ray spectrographic method of analysis (Hall, 1953). The stains proved to be entirely ferruginous, with the notable exception of the yellowish-brown stain on E. 606 which contained in addition to iron appreciable traces of chromium (Table I). This result was confirmed by Dr. A. A. Moss, using a direct chemical method of analysis. Since chromium was not detected in the Piltdown gravel, or in any other flints from the gravel, there can be no reasonable doubt that this implement has been artificially stained.

TABLE I.—*Composition of stains on Piltdown flints*

		Estimations by E. T. Hall (in milligrams per sq. cm.)	
Specimen		Fe	Cr
E.605	" Palaeolithic tool "	0·8	nil
E.606	" Palaeolithic tool (*in situ*) "	0·5	0·2*
E.607	" Palaeolithic tool "	1·4	nil
E.613	" Palaeolithic flake "	1·6	,,
E.685	Flint from surface	1·2	,,
E.956	" Eolith "	0·8	,,
E.965	" Eolith "	0·5	,,
E.985	" Eolith "	0·8	,,
E.989	Palaeolithic flake-blade	0·2	,,
E.2690	Morris flint	0·1	,,
Unreg.	Sample of gravel	0·9	,,

* Chemical estimation gave *circa* 0·1 mg./sq. cm.

When a small chip was removed from the stained cortex of E. 606 for chemical analysis, the staining was found to be superficial; below its surface the cortex proved to be pure white (Pl. 28, fig. 3C). Yet in brown flints normally found in the Piltdown gravel the cortex is iron-stained throughout its thickness. Flint nodules with white cortex do not occur naturally in the Piltdown district.

Apart from their orange or brownish staining the Piltdown " palaeoliths " could quite easily be matched in the flint waste found at flint-mining or chipping sites of Neolithic or later age on the Chalk Downs of Sussex. Dawson was perhaps not far from the truth when he wrote of the Piltdown " palaeoliths " as follows : " They resemble certain rude inplements occasionally found on the surface of the Chalk Downs near Lewes, which are not iron stained " (Dawson & Woodward, 1913 : 122, footnote 2). The battered aspects of these specimens (Pl. 28, fig. 3A–C), suggest that they may have originated through fortuitous shattering of flint hammerstones or anvils. Such accidentally fractured pieces are not uncommon on downland flint workshop sites. Specimens E.605 and E.606 show no signs of use, which is in accord with their being waste pieces. Some attempt has been made to shape two of the edges of the thick flake E.607, but randomly broken pieces were sometimes selected for use either as cores or as occasional tools by the Neolithic and Early Bronze Age flint workers.

Thus it appears that the only flints found at Piltdown which Dawson and Woodward considered worthy of figuring as probable palaeolithic implements show features which are difficult to explain unless they were brought to the site from elsewhere and, having been suitably stained, planted in the gravel for the excavators to find. The fact that the pieces in question are crude and atypical (in the words of Ray Lankester[1] " unlike any known or defined industry ") suggests that they may have been chosen so that they could be compared with the poorly defined and altogether dubious artifacts which had then recently been found below the Red Crag of Suffolk (Moir, 1911). Whether in fact any artifacts occur *in* the Piltdown gravel is now doubtful. No humanly fractured flint was noted during recent excavations (Toombs, 1952) ; all the artifacts previously reported were either surface finds or were introduced fraudulently.

A broken nodule of black flint with heavily bruised edges was found by Woodward in the sandy layer overlying the basal gravel ; he suggested that it may have been used as a hammerstone (Woodward 1917 : 2). In fact it bears more resemblance to a broken paving cobble bruised by cart-wheels than to a prehistoric hammerstone.

(II) THE BONE " IMPLEMENT "

(Pl. 29, figs. 7–10)

Next to the skull, mandible and canine tooth, the most remarkable find at Piltdown (but not *in situ*) was an object shaped like the blade of a cricket bat, which had been made out of a strip of bone from the femur of a large extinct elephant. Woodward regarded it as possibly belonging to the Lower Pleistocene *Elephas meridionalis*, but it could equally well have come from one of the larger Middle Pleistocene species. Dawson & Woodward (1915) regarded the object as an implement which had been shaped by " a primitive tool, presumably a flint " when the bone " was in a comparatively fresh state." These conclusions were challenged at once when their paper was read before the Geological Society. Reginald Smith said " the possibility of the bone having been found and whittled in recent times must be considered," and A. S. Kennard doubted whether the bone had been cut when it was fresh. No comparable bone work has ever been found in known Palaeolithic industries and recent experiments have shown (*a*) that the facets on the Piltdown specimen bear no resemblance to the scratchy marks made on bone by a flint knife, nor, as Breuil once suggested (1938), to the cuts of beavers' teeth, but must have been made by an even-edged metal blade ; (*b*) that it is practically impossible to whittle a fresh or recently dried bone, which can only be worked by flaking, scraping, sawing or grinding ; and (*c*) that some fossilised bones, having more the texture of chalk, are readily carved. Plate 29, fig. 10, illustrates a fossil bone from the Swanscombe gravels which was whittled with a steel razor and then stained with a ferric solution and varnished to reproduce as nearly as possible the present appearance of the cut surfaces of the Piltdown specimen.

In conclusion, the Piltdown bone " implement " is a piece of the femur of a fossil elephant, obtained probably in two weathered pieces from a Middle Pleistocene brickearth or sandy formation. The ends were whittled with a steel knife, and the newly cut surfaces were stained with an iron solution. The small fragments of bone, now chemically shown to be from the same original source, which were found in the basal clay suggested to the excavators that the implement belonged to that level (see p. 253).

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[1] *In lit.* to A. S. Woodward, 31st Jan., 1913.

4. THE PILTDOWN MAMMALIA

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BETWEEN 1911 and 1914 eighteen fossil mammalian bones and teeth were found at, or in the immediate vicinity of, the Piltdown skull site. Four were recorded as having been found *in situ* in or below the chocolate-coloured basal gravel, two on the surface of the adjoining field and the remainder on the spoil heaps at the edge of the small pit. Considering the thinness of the gravel (average thickness 18 in.), the small size of the pit (less than 50 × 10 yards in area), and the extreme rarity of fossils in the Pleistocene river gravels of Sussex, this was a remarkable yield.

The fossils are heterogeneous in character, ranging from a heavily rolled enamel cap of a Mastodon tooth to a large piece of cervid antler with almost undamaged surface. Apparently they were not scattered through the gravel but were confined to one or possibly two pockets. Woodward (1948) wrote :

" After Mr. Dawson's death in 1916, I was able to open a series of pits along the other side of the hedge in a field adjacent to the original pit. There I was helped by Professor Elliot Smith . . . and others. We began close to the spot where the skull was found and worked in both directions from that place. Our efforts however were all in vain. We found nothing of interest in the gravel."

In 1950 a further trench, 4 ft. × 32 ft., was dug in undisturbed gravel by the Nature Conservancy, and all the excavated material was sieved and carefully examined, but no bones nor teeth were found (Toombs, 1952).

Some of the Piltdown fossils (" *Stegodon*", *Mastodon arvernensis* and *Rhinoceros* cf. *etruscus*) are undoubtedly Villafranchian (" Upper Pliocene " of earlier authors, but now classed as Lower Pleistocene) ; but others are not older than Middle or Upper Pleistocene. When they were first described there was some question as to whether gravels of two ages were present. Dawson concluded : " It is clear that this stratified gravel at Piltdown is of Pleistocene age, but that it contains in its lower stratum, animal remains derived from some destroyed Pliocene deposit probably situated not far away, and consisting of worn and broken fragments" (Dawson & Woodward, 1913 : 123). In a later paper he wrote : " We cannot resist the conclusion that the third or dark bed is in the main composed of Pliocene drift . . . " (Dawson & Woodward, 1914 : 85).

(i) *" Derived " or Villafranchian Group*

With the increase of knowledge, the presence of " Pliocene " (Villafranchian) mammalian remains at Piltdown became increasingly difficult to explain, for, with one significant exception (see Table II footnote), none has been found elsewhere in southern England. If they were to be found *in situ* in Sussex, they would be expected in terrace or plateau deposits not less than 200 ft. above the level of the Ouse, but Edmunds (1926 : 68) demonstrated that the Piltdown gravel is part of a terrace 50 ft. above the Ouse (see p. 273). Thus it seemed that they could only have come from a block of indurated fossiliferous sand which worked its way down from a higher level and disintegrated on the Ouse flood-plain in 50-ft. terrace times.

When it had been established that the Piltdown mandible was a forgery it became probable that the Villafranchian fossils were also introduced in order to suggest that " Piltdown Man " dated from Pliocene times.

In his original description of one (E.596) of the three pieces of molar tooth referred to " *Stegodon* " Woodward wrote : " It cannot be referred to the upper Pliocene *Elephas meridionalis*, because in this species the valleys are deeper in proportion to their width, while the ridges are more plate-like and parallel in their upper portion. The new specimen is, therefore, of an earlier Pliocene type which is best known from the Siwalik Formation in India and has not hitherto been found in Western Europe " (Dawson & Woodward, 1913 : 142). Later, the Piltdown specimens were compared to *Elephas planiforns*, of the Upper Siwaliks, now regarded as Lower Villafranchian. There are no specimens comparable with *E. planifrons* from the English Red Crag in the British Museum nor in the Geological Survey collections. That three pieces of *Elephas* cf. *planifrons* should be recorded at Piltdown might therefore be regarded as very remarkable. In their reddish colour the Piltdown pieces resemble Red Crag fossils, and also closely match the Piltdown hominoid remains. This similarity in colour led some investigators to conclude that in spite of their unrolled condition the Piltdown skull and mandible were of Villafranchian age (Hopwood, 1935).

If the "*planifrons*" molar fragments were introduced at Piltdown it is probable that they were obtained from some foreign source and artificially stained to match the Piltdown cranial bones and mandible. The Piltdown mandible was given a rich mahogany colour by a process which involved the use of iron and chromium compounds, and it appeared likely that the same method would have been applied to imported "*planifrons*" teeth. Samples of the iron-stained cementum of the two critical specimens from Piltdown (E.596 and E.620) were analysed spectrographically in the Department of the Government Chemist by Mr. H. L. Bolton, who reported that they contain significant traces of chromium (*circa* 0·3 and 0·1% respectively).

Any remaining doubt that these pieces of "*planifrons*" molars were of foreign origin was dispelled by their radioactivity. In the hope of tracing the origin of these pieces a series of mammalian teeth from the main Villafranchian localities was included among the fossils selected for the tests (p. 276). The results obtained reinforce the conclusion that the Piltdown specimens were not obtained from an English deposit. The uranium content of fossil teeth, while increasing with geological age, is subject (as fluorine is) to considerable fluctuation from place to place. Nevertheless it appears that within relatively uniform strata of limited extent the ratio of the extremes of the variation in comparable material does not generally exceed the value of three. Thus a specimen consisting largely of dentine or cementum with a radioactivity of 200 net counts per minute is extremely unlikely to have come from a deposit such as the Red Crag in which random samples of teeth show a maximum radioactivity of less than 30 c.p.m. Uranium (again like fluorine) is adsorbed more readily by cementum and exposed dentine than by enamel, and on an average, the radioactivity of enamel in a fossil tooth is only about one-third that of dentine or cementum (Pl. 30, fig. 13). The radioactivity figures in Table II are maxima based on samples which were mainly cementum and dentine.

TABLE II.—*Radioactivity of Piltdown elephant teeth compared with mammal teeth from Villafranchian sites*

Source of specimen	c.p.m. (Max.)
" Piltdown " (E.620)	355
" Piltdown " (E.596)	203
" Piltdown " (E.597)	175
*" Portslade " (M.10436)	28
Red Crag, Suffolk	15
Red Crag, Suffolk	13
Red Crag, Suffolk	12
Red Crag, Suffolk	12
Red Crag, Suffolk	9
Red Crag, Suffolk	6
Doveholes, Derbyshire	25
Netherlands (dredged specimen, ? leached)	1
Senèze	15
Puy-de-Dome	<10
Chagny-Bellecroix	5
Val d'Arno	26
Siwaliks	19
Siwaliks	8
Algeria	18
Algeria	15
Morocco	<10
Ichkeul, Tunisia	195

* About 1911 the late Dr. Eliot Curwen obtained some fossils from workmen digging brickearth at Portslade, near Brighton, Sussex, including a well-preserved, grey to buff-coloured, molar of *Ursus arvernensis* (a Villafranchian species of bear) and two complete pale buff-coloured limb-bones of an undetermined species of the same genus, which he presented to the British Museum (Nat. Hist.) where they are registered under M.10436 and M.10571–2. See White 1926, pp. 85–6. The radioactivity of these three specimens proved to be higher than any of the British Pleistocene fossils which have been tested (the Piltdown specimens exluded). Their Lower Pleistocene age therefore seems assured, and since they are not in the condition of derived specimens they can have no natural place in the low-level Portslade brickearth which is Upper Pleistocene. In striking contrast a mammoth molar from the same site and undoubtedly contemporary with the brickearth proved to have a very low radioactivity. There is a strong suggestion that the specimens of *Ursus* had either been "planted" or had been traded by workmen who happened to have access to some collection of foreign fossils.

Fossils from nearly a dozen Villafranchian localities in Europe and Asia were tested, but none showed radioactivity in excess of 28 c.p.m. Professor C. Arambourg enabled us to extend the range of comparison by generously providing specimens from North African localities. A molar tooth originally recorded as *Elephas* cf. *planifrons*, from Garaet Ichkeul in Tunisia, has proved to have a radioactivity closely comparable with the Piltdown specimens. Not only is the count rate in the Ichkeul specimen and E.596 from Piltdown almost identical, but the difference between the activity of the enamel and of the cementum is unusually small in both. There is also close agreement in the fluorine content of these specimens. Ichkeul, 20 km. south west of Bizerta, is a richly fossiliferous locality, at which *Elephas* cf. *planifrons* is stated to be the commonest species represented (Arambourg & Arnould, 1950 : 155).

		$\frac{\%F}{\%P_2O_5} \times 100$	p.p.m. eU_3O_8
Piltdown " *planifrons* " molar E.596	dentine and cementum	8·2	610
	enamel	1·8	520
Piltdown " *planifrons* " molar E.620	dentine and cementum	7·9	1060
	enamel	2·6	170
Ichkeul " *planifrons* " molar	dentine and cementum	8·4	580
	enamel	2·7	<480
Siwalik *planifrons* molar	dentine and cementum	7·1	>56
	enamel	2·0	45
Siwalik *planifrons* molar, dentine and cementum		7·3	>24

Proof that three Villafranchian mammalian teeth were introduced into the Piltdown gravel suggests that the others were also introduced. The molars of *Mastodon* and *Rhinoceros* showed no evidence of artificial staining, but to judge from their colour, mineralization and radioactivity, it appears probable that they were obtained originally from the Red Crag of East Anglia.

(ii) " *Contemporary* " *Group*

Division of the Piltdown mammalia into a derived Villafranchian group and a later group contemporary with the deposition or re-arrangement of the gravel was mainly based on the known ranges of the genera and species represented ; colour and state of mineralization of the specimens were also taken into consideration. None of these criteria proved altogether satisfactory. Hopwood (1935) divided the specimens into a dark-coloured, heavily mineralized group, comprising the teeth of " *Stegodon* " (*Elephas* cf. *planifrons*), *Mastodon*, *Rhinoceros* and *Hippopotamus*, and a paler, less mineralized group, including the remains of *Equus*, *Cervus* and *Castor*. He pointed out, however, that *Hippopotamus* had never been recorded in England from deposits earlier than the Cromer Forest Bed and that the broken edges of the molar from Piltdown were sharp, suggesting that it was not a derived specimen. Moreover, the edges of two of the fragments of " *planifrons* " molars were also sharp, and since there could be no question of the geological age of these pieces, it had to be admitted that some Villafranchian specimens had found their way into the Piltdown gravel without being rolled. This important observation suggested that the dark-coloured but unrolled pieces of the Piltdown skull could belong to the older or Villafranchian fauna. This had been the opinion of E. T. Newton, and was admitted as a possibility by Dawson (in Dawson & Woodward, 1913 : 151), although he was more inclined to regard " *Eoanthropus* " as contemporary with the later, Pleistocene fauna.

The fluorine-dating method seemed a suitable means of checking the relative ages of the Piltdown remains, and the results (Oakley & Hoskins, 1950) did agree broadly with the palaeontological dating of the mammalian remains. All the undoubted Villafranchian teeth (*Elephas* cf. *planifrons*, *Mastodon*, and *Rhinoceros* cf. *etruscus*) showed a very high fluorine content (1·9–3·1%), whereas the remainder, all of which could be post-Villafranchian, showed considerably less (0·1 to 1·5%). But the range of fluorine content in the probably post-Villafranchian specimens was far greater than was to be expected in fossils of a single age-group, and it was therefore inferred that the Piltdown gravel had been re-arranged, and new mammalian remains introduced, on several occasions.

According to the results obtained, all the "*Eoanthropus*" material contained on an average the same small amount of fluorine as the bones and teeth of *Castor*. This seemed to confirm Dawson's opinion that the beaver remains were the only fossils from the pit that were contemporary with "Piltdown Man" (Dawson & Woodward, 1914 : 86).

One other fossil recorded from the Piltdown gravel showed an equally low fluorine content : the molar tooth of *Hippopotamus*, which Hopwood placed in the Villafranchian group on account of its dark colour. Its enamel is colourless and almost unaltered, but its dentine, containing $< 0{\cdot}05\%$ fluorine, is stained brownish black throughout. The low fluorine content appeared to indicate that it was not derived from an older geological formation, but belonged to the latest faunal group in the gravel. Yet its preservation is quite unlike that of the associated teeth of *Castor*. Considering that the "*planifrons*" molars from Piltdown had been artificially stained and then introduced at the site, the colour of the *Hippopotamus* molar suggested that it, too, had a similar history. This was confirmed by spectrographic analysis carried out in the Department of the Government Chemist by Mr. H. J. Dothie, who found that the dark-coloured dentine contained 1% of chromium, a clear indication of artificial staining.

Drs. Weiler and Strauss (see below, also Table V) showed that this tooth has an unusually high ash content, and a correspondingly low organic content. This and its exceptionally low fluorine content suggests that it could only have come from a limestone cave deposit, in which fluorination of bones and teeth is usually minimal, *Hippopotamus* has only somewhat rarely been reported from British caves, but occurs abundantly in the calcareous cave deposits of the Mediterranean islands. Some of the molars from the Ghar Dalam Cave in Malta correspond in size with the Piltdown specimen, and have a low fluorine content combined with a low organic content. The Maltese teeth are creamy white in colour. Experiments in the Department of Minerals showed that by soaking one of the Maltese specimens in a solution of ferrous sulphate or iron alum, precipitating the iron as ferric hydroxide, and then treating with tannic acid to produce a blackish tinge the colour of the Piltdown molar could be reproduced exactly.

	Percentages						
	N	C	H_2O	F/P_2O_5 ($\times$ 100)	$CaCo_3$	Ash	p.p.m. $eU_3\ O_8$
Dentine of Recent teeth .	>2	>6	>13	$<0{\cdot}3$	5	<60	<1
Piltdown hippo molar dentine	0·06	2	12	0·3	2	84	3
Ghar Dalam hippo molar ,,	nil	nil	7	0·3	14*	87	7

* After staining in an iron sulphate solution this was reduced to 5 per cent.

The presence of chromium in the specimens from Piltdown suggests that they were treated with chromic acid or a dichromate solution with the idea of aiding the oxidation of a ferrous staining agent. If an iron sulphate had been used, it might account for one other feature of the composition of the Piltdown *Hippopotamus* molar, namely, the presence of calcium sulphate.

In 1949 an X-ray powder diffraction photograph of the blackened dentine, taken in the Government Chemist's Department, revealed the presence of calcium sulphate. Using the same technique Dr. G. F. Claringbull later detected calcium sulphate (gypsum), apparently partly replacing the calcium phosphate, in several of the bones and teeth from Piltdown. With Dr. M. H. Hey he has shown (p. 268) that the gypsum could be the result of artificial treatment of the specimens, and probably originated through interaction of the calcium phosphate of the bone or dentine and a solution of an acidic iron sulphate.

Tests carried out by Dr. C. Bloomfield of Rothamsted Experimental Station showed that, at the present day, SO_3 (sulphate) ions are unusually low in the Piltdown gravel, hence it is not possible to maintain that the sulphate-bearing specimens owe their composition to some natural mineralizing process peculiar to the deposit. No gypsum crystals could be detected by X-ray analysis of the fine fraction of the gravel.

Eventually samples of all the Piltdown mammalian specimens were examined for the presence of chromium, either spectrographically in the Department of the Government Chemist, or chemically in the Department of Minerals of the British Museum, where they were also submitted to X-ray crystallographic analysis (see p. 269).

Several of the results obtained are worth commenting on here. Chromium and gypsum were detected in a premolar of *Hippopotamus* (the first Piltdown fossil shown to Woodward), proving that it too had been artificially stained. This tooth, having a higher fluorine content (1·1%), presumably did not come from the same source as the molar. But both the hippopotamus teeth are less radioactive than any Pleistocene fossils from sand or gravel that have been tested (see Table XI), suggesting that they are from calcareous or argillaceous deposits, for it is known that phosphates are less prone to adsorb uranium where the strata are rich in calcium carbonate or consist largely of clay (Davidson & Atkin, 1953 : 27).

Chromium was also found in the longitudinally split portion of a *Cervus* metatarsal (Dawson & Woodward, 1913 : 121, 142), which had been included in the so-called contemporary group. No sulphate was detected in this bone, indicating that the staining solution used either was not sulphate, or was not sufficiently reactive to cause replacement of the phosphate. A few specimens in the "contemporary" group, including the mandible and incisor of *Castor fiber*, were found to contain calcium sulphate, but no chromium. These were presumably stained by another technique, which dispensed with the use of a dichromate solution as oxidizer.

The fluorine and organic content of the beaver mandible could be matched among bones from either Late Pleistocene or Holocene deposits.

In addition to the artificially stained mandibular fragment and incisor, the Piltdown collection includes two molars of *Castor fiber*. They both show superficial iron-staining which may be artificial. One of the molars was left in its gravel matrix. This seemed to be visible proof that the Piltdown gravel did in fact contain fossils, but on examination the block containing the tooth proved to be an artifact. When soaked in water it began to break down, revealing that it consisted largely of loamy material with a concentration of pebbles on the outside. When the water in which the block had been soaking was evaporated there was a large amount of gummy residue (0·8 gm.). According to its former label one of the pieces of "*Stegodon*" teeth (E.620) was also kept for a time in a similar lump of hardened gravel (see also Dawson & Woodward, 1914 : 84).

One of the fragments of a cream-coloured bone said to have been found *in situ* in clay at the base of the Piltdown gravel (and regarded by Dawson and Woodward as indicating the source of the worked slab of elephant femur) is still embedded in a lump of loam, adhering to the middle of a slab of ironstone. On close examination the loamy matrix shows every indication of being faked. It contains small scattered pebbles set at various angles, and its shows cracks and bells of burst air-bubbles such as appear if loamy matter is worked into a paste and then allowed to set. The sliver of bone embedded in this artificial matrix is identical in composition with the worked elephant bone which, to judge from its state of mineralization and radioactivity, could have been obtained from one of the brickearths in the 50-ft. terrace of the Thames or from an equivalent deposit in the Somme Valley.

	$\frac{\% F}{\% P_2O_5} \times 100$	p.p.m. eU_3O_8
Elephas femur (worked), Piltdown	4·2	10
Fragment from "base of gravel," Piltdown	4·2	9
Cervus antler, Piltdown	5·4	11
Elephas metatarsal, Crayford Brickearth	—	8
Rhinoceros ulna, Crayford Brickearth	3·5	—
Elephas astralagus, Ilford Brickearth	—	33
Rhinoceros astralagus, Menchecourt Sands, Somme	3·4	(10)*

* Estimation based on an associated specimen.

The base of an antler of red deer, *Cervus elephus*, and an upper molar of *Equus* cf. *caballus* (Irving, 1913) were found together in the adjacent field to the west of the gravel pit, "on the surface close to the hedge" (Dawson & Woodward, 1913 : 121). Neither bears any sign of having been rolled on the river bed. In its fluorine content and radioactivity the stag antler is closely comparable with the worked elephant bone. The horse tooth has a much lower fluorine content and shows no radioactivity, indicating that it was derived from a different deposit. The surfaces of both the horse tooth and the stag antler show patchy red iron-staining which recalls in appearance the artificially stained flints (p. 244).

Of the eighteen specimens of fossil mammals recorded from the Piltdown gravel by Dawson and Woodward, ten are unquestionably frauds, and there are strong grounds for believing that this is also true of the remainder. Since the gravel is decalcified (pH 6.5) it is probably unfossiliferous.

5. THE COMPOSITION OF THE PILTDOWN HOMINOID REMAINS

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(1) THE MANDIBLE AND TEETH

THE discovery in the autumn of 1953 that the Piltdown mandible contained the same amount of nitrogen as fresh bone might be regarded as proving its modernity beyond all doubt. In actual fact, however, this would not have been conclusive evidence without the cross-check provided by fluorine analysis. Thus, an ulna of woolly rhinoceros (M.12575) found at a depth of 42 ft. in an Upper Pleistocene river deposit on the site of Lloyd's in the City of London (Warren Dawson, 1925) has a nitrogen content about the same as that of the Piltdown mandible. The reason for the remarkable preservation of the rhinoceros bone is that it was embedded in an unoxidized clay—an environment in which bone-protein decays very much more slowly than in the oxidizing environment of sand or gravel. In marked contrast, a fragment of mammoth femur (M.12946) found at a depth of 20 ft. on the same site, and of the same general age, but preserved in sand, was found to contain very little nitrogen. Fortunately the fluorine content of bone increases at about the same rate in sand (or gravel) and in clay. Thus the fluorine content of the rhinoceros bone is almost the same as that of the mammoth bone.

			% N	% F
Upper Pleistocene bones from Lloyd's site	*Rhinoceros*, in clay	*av.*	3·4	1·1
	Elephas, in sand		0·1	1·3
Piltdown mandible, " in gravel "			3·9	<0·03
Fresh mammalian bone			4·1	0·03

If the Piltdown mandible had occurred naturally in the shallow Piltdown gravel (early Upper Pleistocene) it should not have contained more nitrogen than the skull bones. Moreover, its *fluorine* content should have been greater than that of fresh bone no matter whether the matrix were clay or gravel.

In one account of finding the mandible Woodward (1948 : 11) wrote : " It had evidently been missed by the workmen because the little patch of gravel in which it occurred was covered with water at the time of year when they reached it." At an early stage in the present investigation it had to be borne in mind that conditions in the Piltdown gravel might have been exceptional and that reducing conditions in the basal bed had preserved collagen in the bone. Through the courtesy of the Director of the Rothamsted Experimental Station the chemical conditions in the Piltdown deposits were recently examined by Dr. C. Bloomfield, who found that the "redox potential" in the basal bed indicated oxidizing, not reducing, conditions.

In March, 1952, Professor J. T. Randall and Dr. A. V. W. Martin undertook to examine the collagen in samples of the teeth by means of the electron-microscope. The first results were inconclusive, for in drilling the samples frictional heat had probably de-natured the collagen. Early this year a new attempt was made to determine the state of collagen in the mandible. A small piece of the bone was sawn out and submitted to Dr. Martin, together with a similar sample of the cranium and other selected controls. Electron-micrographs of the decalcified residue of the mandible sample revealed the presence of fairly well preserved collagen fibres with characteristic banding at intervals of 640 Ångström units (Pl. 30, fig. 11), whereas electron-micrographs of samples of the skull showed no trace of collagen fibres. A residue of the Lloyd's rhinoceros bone also proved to contain collagen fibres, but they were partly de-natured and showed only vague shadows of the original banding. The only fossils in which collagen fibres have been found previously are from frozen ground—see Randall *et al.*, 1952. Collagen is denatured at 70°–100° C.

It has been suggested that collagen fibres may be preserved intact through the action of peat acids, but none was detected in a sample of human bone with undiminished nitrogen content from Holocene peat at Branston, Nottinghamshire, nor in a sample of human skin from the Tollund Bog, Denmark (kindly supplied by Dr. Knud Thorvildsen of the National Museum Copenhagen).

Estimation of the fat content of the mandible, suggested by Heizer & Cook (1954 : 94) as a possible means of confirming its modernity, was considered impracticable with a sample of the limited size available for such a test.

In addition to the nitrogen content, the organic carbon, water and ash contents of the mandible have been determined and compared with those of selected controls. The results confirm that this bone is modern, and also show that such artificial treatment as it received has affected the organic fraction only very slightly.

	% N	% C	% H_2O	% Ash
Modern ungulate limb-bone	(4·0)	14·0	24·5	(53)
,, ,, ,, 2nd sample	(4·1)	10·3	21·2	—
Piltdown mandible	(3·9)	14·5	25·0	(61)
Piltdown (left parietal)	1·4	6·1	17·8	62
Neolithic human skull, Coldrum	1·9	6·3	18·2	71
Lloyd's rhinoceros ulna	3·4	10·4	18·9	(67)
Lloyd's mammoth femur	0·1	2·6	10·8	(82)

Note.—The figures in brackets are determinations made on separate samples and therefore independent of other figures on the same line.

The dark mahogany colour of the mandible, matching that of the skull bones very closely, is relatively superficial. Drilling revealed that the interior tissue is buff to pale grey in colour, suggesting that the organic matter filling the pores of the bone prevented the iron-staining solution from penetrating deeply. When the mandible was being drilled with a dental burr to procure an adequate sample for the re-determination of fluorine, there was an odour of burning, and the ejection consisted of minute shavings. When the skull bones were drilled in the same way there was no odour, and the sample consisted of powder.

The mandible shows practically no radioactivity (see Tables X, XII), which is a further confirmation of its modernity.

The fluorine content of the canine and of the molars in the mandibular ramus was estimated in 1949 as $< 0{\cdot}1\%$, but as the mandibular bone itself appeared to contain *c.* 0·2%, and as the probable experimental error on samples of the small size then tested was known to be about ± 0·2% (Oakley & Hoskins, 1950, 379–80), there seemed no reason to regard the canine or the mandible as more recent than the human cranium, with fluorine content estimated to vary from 0·1 to 0·4%. In 1953, new samples of the teeth and of the skull bones were submitted to the Department of the Government Chemist, where Mr. C. F. M. Fryd had devised a technique for estimating smaller amounts of fluorine than could be measured in 1949. The experimental error in the determination of fluorine obviously depends on the size of the sample and the amount of fluorine it contains. The fluorine content of the Piltdown skull bones was determined in 1953 as 0·14 to 0·18%, and the limits of error as ± 0·02%. Where the amount measured was exceptionally small, the fluorine content was recorded as less than $0{\cdot}0x\%$, the true figure lying between $0{\cdot}0x$ and zero. In 1953 all the determinations of the fluorine content of the Piltdown mandible and teeth proved to lie between 0·04% and zero. These results indicated that whereas the skull bones were probably prehistoric, the canine tooth, the mandible and the isolated molar were modern. This conclusion was reinforced by comparing the nitrogen content of the Piltdown bones and teeth (dentine) with that of modern and fossil specimens.

In order to eliminate any possibility that the nitrogen found in the dentine samples was not original but due to contamination of the samples, their organic carbon was also determined. The carbon/nitrogen ratio in the molars and in the canine proved to be slightly lower than in the dentine of two modern teeth which were used for comparison, but approximately the same as in the organic matter of bone (2·296 ± 0·266, Cook & Heizer, 1952 : 4).

	% N	% C	C/N
Modern beaver molar (old individual)	2·2	6·5	3·0
Modern orang-utan canine	3·9	12·8	3·2
Piltdown canine	5·1	12·1	2·3
Molars in Piltdown mandible	4·3	10·0	2·3
Isolated Piltdown molar	4·2	10·7	2·5

In 1950 Dr. David B. Scott of the National Institute of Dental Research, Bethesda (Maryland) undertook to examine collodion replicas of the surfaces of the Piltdown teeth, using the metal-shadowing technique which he has developed with Wyckoff (1946). After examining replicas of the buccal surfaces of the molars in the Piltdown mandible, Dr. Scott reported that " they are not readily recognizable as ancient teeth, since they show very little evidence of post-mortem damage". But, in contrast, replicas of the isolated molar and of the crown of the canine near the tip revealed considerable damage. These findings agree with the results of the present detailed re-examination, that the molars in the mandible have been artificially abraded only on the occlusal surfaces, whereas in the canine and isolated molar the buccal surfaces also have been smoothed artificially.

The black coating on the canine is a paint made from a natural bituminous earth containing iron oxide, probably Vandyke brown (see p. 272). If bituminous matter were not out of place in a highly oxidized gravel it might have been regarded as a natural incrustation. It should also be recorded that Dr. Claringbull found a minute spherule of an iron alloy embedded in the coating on the labial surface of the crown.

The pulp cavity of the canine contains 19 loose sand grains, mostly radio-opaque. Some were extracted for examination and proved to be pellets of limonitic ironstone identical with those which occur in the sand-fraction of the Piltdown gravel. As seen in the radiograph of this tooth (Weiner, Oakley & Le Gros Clark, 1953, pl. 9, fig. 4), all the grains are 1–2 mm. in diameter. If they had been naturally washed into the cavity finer grade material would be expected to have entered with them, for 30% of the grains in the sand-fraction of the Piltdown gravel are *less* than 1 mm. in diameter. The cavity has been sealed by an ovoid grain of hard limonitic ironstone tightly wedged into the aperture of the truncated apex.

(II) THE PILTDOWN SKULL BONES

As the fluorine and nitrogen content of the cranial bones were consistent with their being fairly ancient, it seemed at first that the hoax had been based on a genuine discovery of portions of a skull in the gravel, and that the animal remains and implements had been subsequently " planted " to suggest that it was Pliocene or Early Pleistocene in age. As the investigations proceeded the skull too became suspect. Dr. G. F. Claringbull carried out an X-ray crystallographic analsyis of these bones and found that their main mineral constituent, hydroxy-apatite, had been partly replaced by gypsum. Studies of the chemical conditions in the Piltdown sub-soil and ground-water showed that such an unusual alteration could not have taken place naturally in the Piltdown gravel. Dr. M. H. Hey then demonstrated that when sub-fossil bones are artificially iron-stained by soaking them in strong iron sulphate solutions this alteration does occur. Thus it is now clear that the cranial bones had been artificially stained to match the gravel, and " planted " at the site with all the other finds. The presence of chromium in some of the bones is now more readily explicable, for a dichromate solution might have served to aid the oxidation of iron salts used in staining the bones.

Since all the " local Upper Pleistocene " fossils with comparable composition have proved to be fraudulent introductions, the low fluorine content of the skull indicates that it is more probably post-Pleistocene than Pleistocene in age.

In 1912, no organic matter could be detected in the small piece of the Piltdown I calvaria submitted for analysis to Mr. S. A. Woodhead, Public Analyst of East Sussex (Dawson & Woodward, 1913 : 121). The specific gravity of the powdered fragment was also measured (2·115) ; but neither of these determinations was significant so long as no comparison was made with the mandible. The first physical comparison between the mandible and the calvaria fragments was recorded in a note dated 1925 by Dr. A. T. Hopwood, who found that their specific gravities, measured *in vacuo*, were as follows :

Mandible 2·06 ; Piltdown I occipital 2·13 ; Piltdown II frontal 2·18.

The specific gravities of the Piltdown II occipital and isolated molar have been determined more recently as 2·20 and 2·18 respectively. If allowance is made for the density of the molars, the specific gravity of the bone of the mandible becomes 2·05. The difference between the specific gravity of the mandible and of the calvaria would possibly have been greater if the constituent apatite had not been so extensively replaced by gypsum, which is a lighter mineral, although additional iron oxide may have counterbalanced this effect.

The age of the Piltdown skull has been questioned on the score that it included nasal bones in close association (Marston 1950 : 293). Unless ankylosed before death the nasal bones have commonly separated even in recent burials. It was therefore difficult to understand their occurrence together in the upper disturbed layer of the gravel (Dawson & Woodward, 1914 : 84). However, there was always the possibility that the nasal bones did not belong to the Piltdown skull. These bones show partial replacement by gypsum, indicating that they were artificially iron-stained. To judge from their composition they were not obtained from the same source as the other cranial fragments. In drilling samples from the nasal bones the ejection consists of shavings (as when the Piltdown mandible was drilled). This is not a proof that a bone is modern, for the property of peeling under the shearing action of a rotating burr is a function of the extent to which the collagen ground-mass of the bone is preserved ; and under exceptional conditions this has persisted intact even since Pleistocene times.

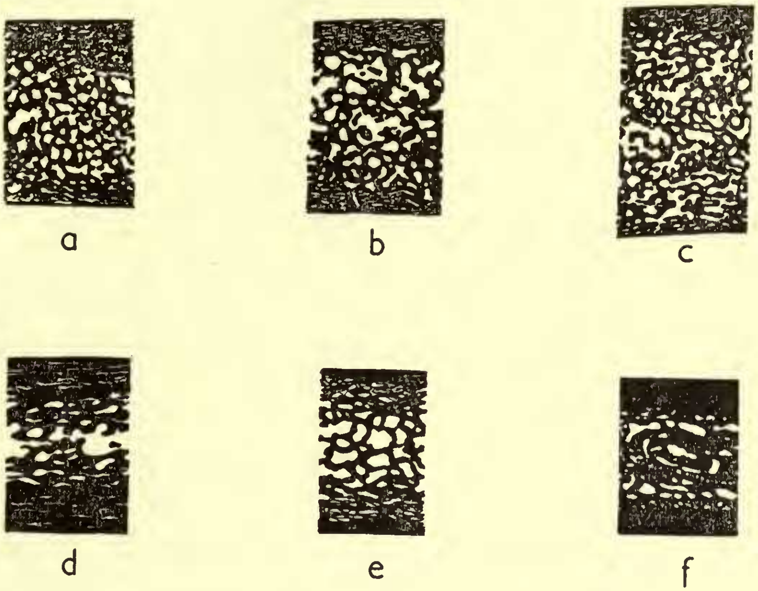
	Percentages				
	F	N	C	H_2O	Ash
Fresh bone	0·03	4·1	14·0	25	53
Piltdown nasal bone . . .	0·21	3·9	20·9	27	59
Piltdown " turbinal " . . .	0·28	1·7	6·1	25	58
Piltdown I calvaria (*maxima*) .	0·18	1·9	7·5	19	76 (*min.* 62)

Apart from the artificial staining, the Piltdown nasal bones differ from normal fresh bone only in their fluorine content, which is in excess of that found in recently buried skeletons except in areas of endemic fluorosis (Bell & Weir, 1949 : 89), or possibly where the soil has been treated with fluorine-rich phosphate fertilisers.

The great thickness of the Piltdown cranial bones is remarkable (e.g. maximum thickness of the parietals 12 mm.), but not unique. Cross-sections of the bones show that the thickness is accounted for by an expansion of the diploe tissues ; the inner and outer tables are relatively very thin. In all those palaeolithic skulls with very thick cranial walls that have been examined histologically, the tables are nearly as thick or even thicker than the diploe (Text-fig. 5). In its structure and thickness the Piltdown skull can be matched exactly among some recent crania, for example a skull of an Ona Indian from Tierra del Fuego in the British Museum collection

(1938.8.10.2). However, such skulls are undoubtedly rare, and to find *two* in the same condition at one site would be most unlikely.

The thickening of the diploe in the cranium may be a reflection of a severe chronic anaemia. The late Professor S. G. Shattock, who examined the Piltdown skull from the viewpoint of a pathologist reported (1913 : 46) :



TEXT-FIG. 5. Thin sections of parietal and frontal bones of Piltdown and other human skulls. *a*, Piltdown I, parietal ; *b*, Piltdown II, frontal ; *c*, Ona Indian, parietal ; *d*, Swanscombe, parietal ; *e*, Fontéchevade II, parietal ; *f*, Gibraltar I, parietal ? *a–e* drawn from original specimens ; *f* based on drawing by Shattock (1913). × 3. *del. D. E. Woodall.*

" Certain details of the Piltdown calvaria ... suggest the possibility of a pathological process having underlain the thickened condition. These are : (1) The extreme thinness of the tables ; the diploe is closed in on either aspect with the thinnest compact lamina ; such as can be matched ... [an ancient Egyptian parietal is quoted] where the thickening ... is incontestably the residue of a morbid process. (2) The presence of the elevated patches on the inner surface of certain of the fragments already detailed : in the modern adult skull such fine vascular furrows as there may have been during growth, on the inner aspect of the tabular bones, have been smoothly filled in. And (3) to this may be added the synostosis which has here and there taken place at the sutures although the age of the individual is approximately only 25 years."

The fragments of the so-called second Piltdown skull have also been artificially stained, for they contain chromium and show partial alteration to gypsum. They comprise a small piece of occipital bone and part of a right frontal of unusual thickness. The occipital fragment is not remarkable in thickness or any other morphological feature, but its neat rectangular outline suggests that it has been trimmed to that shape. The frontal fragment is also rectangular as though broken deliberately. This latter piece could belong to the first cranium, with which it agrees in its exceptional thickness and unusual structure, yet in its total composition it appears to have rather more in common with the occipital fragment grouped with it than with the occipital or other bones of the first skull.

	Percentages								*p.p.m.*
	N	C*	$CaCO_3$	P_2O_5	F/P_2O_5 (× 100)	Fe	$CaSO_4$	Cr	eU_3O_8
Piltdown I :									
Left fronto-parietal (*av.*)	1·1	6·8	3·9	18·7	0·8	6	+	1·5	3
Left temporal	0·2	4·8	3·6	23·2	0·8	8	++	0·7	1
Right parietal	1·4	5·3	3·0	19·8	0·8	5	++	0·0	<1
Occipital	0·3	6·8	4·5	20·8	0·7	6	++	0·2	2
Piltdown II :									
Right frontal	1·1	4·4	1·5	14·6	0·8	10	++	<0·1	<1
Occipital	0·6	3·9	2·0	13·6	0·2	9	++	<0·1	0

* Carbon in organic fraction.

However, when the analyses are compared, it appears possible that the resemblances between the two fragments of the Piltdown II group are not original but are due to the bones having received the same chemical treatment. The fronto-parietal bone of the Piltdown I group has been less extensively altered to gypsum than the others, and it shows the highest radioactivity, the highest chromium content and the highest carbonate content. The Piltdown II bones, to judge from their high iron, low carbonate and low phosphate content, received a more intensive treatment with an acidic iron salt than any of the Piltdown I bones ; and it seems probable that their lower radioactivity[1], lower chromium content and lower carbon content also reflect differences in treatment.

The feature in the composition of bones which is least likely to be affected by the iron sulphate and chromate treatment is the fluorine/phosphate ratio, and in this the frontal of II agrees with the bones of skull I and not with the occipital which was placed with it.

These more detailed investigations therefore lend further support to the provisional conclusion reached in our 1953 report (p. 145) that the right frontal fragment originally formed part of the first skull. It is probable that the second skull, from which the thinner occipital fragment was obtained, was in a sub-fossil condition similar to that of the first skull.

The human cranial fragments (frontal, parietal and zygomata) reported to have been found by Dawson in gravel of the Piltdown terrace at Barcombe Mills appear to

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[1] It has been suggested that the radioactivity of some of the Piltdown bones may be correlated with traces of K^{40} due to their having been treated with a solution of potassium dichromate. However, direct tests failed to demonstrate any exact correlation between the potassium content of the specimens and either their radioactivity or their chromium content. It is probable that after the bones had been stained some of the potassium ions would have been removed in solution while the chromium ions became fixed.

be pieces of two or possibly three skulls. All these fragments have been artificially iron-stained, by the sulphate process, but unaided by a chromium compound. In composition they are broadly comparable with the Piltdown calvaria, but they differ from all the fragments of these, excepting the occipital of Piltdown II, in their thickness and structure, which approximate more closely to the normal.

The possibility that occipital II belonged to one of the " Barcombe Mills " skulls has been considered, but only the parietal agrees in nitrogen content, and this differs in showing a weak radioactivity which may be original since it cannot be attributed to K^{40} in potassium dichromate. In contrast occipital II shows no radioactivity.

TABLES OF ANALYSES III—VII.

In these tables nitrogen determinations in italics by Mrs. A. Foster, in the Department of Minerals, British Museum (Nat. Hist.), 1953; the remainder of the nitrogen, H_2O and ash determinations by Dr. G. Weiler and Dr. F. B. Strauss in the Microanalytical Laboratory, Oxford, 1954. Inorganic carbonate determined by Mr. C. F. M. Fryd (see p. 266), in the Department of the Government Chemist; organic carbon (C) calculated from his figures and those of Drs. Weiler and Strauss.

Phosphate (P_2O_5), fluorine and iron (Fe) determinations in italics by Dr. C. R. Hoskins (1949–51), the remainder of these by Mr. C. F. M. Fryd (1953–4).

The chromium values in italics are spectrographic estimations made in the Department of the Government Chemist; the remainder of the chromium values are chemical determinations by Dr. A. A. Moss in the Department of Minerals, British Museum (Nat. Hist.).

nil = none detected. + some gypsum detected by X-ray diffraction; ++ much gypsum (in excess of 15% $CaSO_4$). $CaCo_3$ estimated on basis of determination of CO_2. Uranium content expressed as U_3O_8 determined fluorimetrically by Mr. A. D. Baynes-Cope, Department of the Government Chemist, as eU_3O_8 estimated on basis of radioactivity measurements by Mr. S. H. U. Bowie and Dr. C. F. Davidson, Atomic Energy Division, Geological Survey.

Table III.—*Analyses of Piltdown hominoid bones*

Register No.	Description	Percentages											p.p.m.	
		N	C	H_2O	Ash	P_2O_5	F	F/P_2O_5 (× 100)	$CaCO_3$	$CaSO_4$	Fe	Cr	U_3O_8	eU_3O_8
E.590a.	Piltdown I, left parietal	1·9	6·1	17·8	62·4	—	—	—	3·6	+	—	1·50	4	3
E.590b.	Piltdown I, left frontal	0·3	7·5	19·5	72·6	18·7	0·15	0·8	4·1	+	6	1·00	—	
E.591.	Piltdown I, left temporal	0·2	4·8	15·8	75·3	23·2	0·18	0·8	3·6	++	8	0·65	4	1
E.592.	Piltdown I, right parietal	*1·4*	5·3	19·0	68·7	19·8	0·15	0·8	3·0	++	5	nil	2	<1
E.593.	Piltdown I, occipital	0·3	6·8	16·7	76·1	—	—	—	4·5	14·4	—	0·15	8	2
	additional fragment	*1·6*	—	—	—	20·8	0·14	0·7	4·0	+	6	nil	—	—
E.594.	Piltdown I, mandible	*3·9*	14·5	25·0	60·5	20	<0·03	<0·2	6·5	0	3	0·30	nil	<1
E.610a.	Piltdown I, nasals	*3·8*	20·9	26·9	58·5	14·5	0·21	1·5	2·0	++	*c.10*	*nil*	—	<1
E.610b.	Piltdown I, "turbinal"	1·7	6·1	24·9	58·2	16·6	0·28	1·7	1·6	++	*c.15*	*nil*	—	—
E.644a.	Barcombe Mills, frontal	2·4	7·3	21·5	68·5	26·5	0·07	0·3	2·2	++	*c.11*	*nil*	—	1
E.644b.	Barcombe Mills, parietal	0·3	5·0	16·1	73·0	26·0	0·10	0·4	3·0	+	—	nil	—	2
E.644c.	Barcombe Mills, zygoma	1·81	6·9	22·0	62·9	13·4	0·04	0·3	1·1	++	—	nil	—	—
E.646.	Piltdown II, frontal	*1·1*	4·4	18·8	68·2	14·6	0·11	0·8	1·5	++	*c.10*	0·05	—	<1
E.647.	Piltdown II, occipital	*0·6*	3·9	18·6	67·2	13·6	0·03	0·2	2·0	++	*c.9*	0·04	—	0

Table IV.—*Analyses of the Piltdown hominoid teeth.*

Register No.	Description	Percentages									
		N	C	H_2O	Ash	P_2O_5	F	F/P_2O_5 (× 100)	$CaCO_3$	Fe	Cr
E.594.	Piltdown I molars, dentine	*4·3*	10·0	21·0	67·1	26	<0·04	<0·2	5·5	trace	—
E.611.	Piltdown I canine, dentine	*5·1*	12·1	25·4	61·7	22	<0·03	<0·2	5·0	trace	—
E.645.	Barcombe Mills molar, dentine	2·1	7·3	16·1	73·1	26·2	0·10	0·4	6·7	0·6	*nil*
E.648.	Piltdown II molar, dentine	*4·2*	10·7	22·6	56·8	25	<0·01	<0·1	8·0	trace	—

TABLE V.—*Analyses of the Piltdown mammalian bones and teeth*

Register No.	Description	Percentages: N	C	H_2O	Ash	P_2O_5	F	F/P_2O_5 (× 100)	$CaCO_3$	$CaSO_4$	Fe	Cr	p.p.m.: U_3O_8	eU_3O_8
E.595.	*Mastodon* cf. *arvernensis* molar, enamel	—	—	—	—	*23*	*1·9*	*8·3*	—	nil	*5*	*nil*	20	11
E.596.	*Elephas*. cf. *planifrons*													
	molar { cementum .	—	—	—	—	*33*	*2·7*	*8·2*	—	nil	*3*	*c.0·3*	1000	610
	molar { enamel . .	—	—	—	—	37·2	0·66	1·8	9·0	—	*1*	—	—	520
E.597.	*Elephas*. cf. *planifrons* molar, cementum	—	—	—	—	*34*	*2·5*	*7·4*	—	—	*1*	*<0·05*	1000	530
E.598.	*Hippopotamus* molar, dentine	0·06	2·2	11·5	83·8	*37*	*<0·05*	*0·3*	1·8	++	*3*	*c.1·0*	—	3
E.599.	*Hippopotamus* premolar, dentine	0·03	2·8	11·5	78·0	*29*	*1·1*	*3·8*	5·7	+	*5*	*c.2·0*	—	5
E.600.	*Cervus elaphus* antler .	—	—	—	—	*28*	*1·5*	*5·4*	—	nil	*3*	*nil*	—	11
E.601.	*Cervus*, metatarsal . .	0·6	4·1	13·9	77·1	*27*	*0·1*	*0·4*	5·6	nil	*4*	*c.1·5*	—	6
E.602.	*Equus* molar, dentine .	*1·2*	—	—	—	23·7	0·67	2·9	5	+	*4*	*nil*	—	0
E.603.	*Castor* molar, dentine .	2·4	6·1	15·3	71·8	*30*	*0·4*	*1·3*	4·5	nil	*3*	*nil*	—	<1
E.615.	*Elephas* femur, worked .	—	—	—	—	*30*	*1·3*	*4·3*	—	nil	*2*	nil	—	10
E.616.	Bone fragment " from base of gravel."	—	—	—	—	*33*	*1·4*	*4·2*	—	nil	*1*	—	—	—
E.617.	Bone fragment " from base of gravel."	—	—	—	—	26·4	1·1	4·2	8·0	tr.	*3*	—	—	9
E.618.	*Castor fiber* incisor, enamel and dentine	—	—	—	—	*27*	*0·1*	*0·4*	—	+	*c.10*	*nil*	—	<1
E.619.	*Castor fiber* mandible .	*1·8*	7·8	19·8	69·0	19·2	0·28	1·5	4·4	++	*6*	*nil*	—	<1
E.620.	*Elephas* cf. *planifrons*													
	molar { cementum .	0·02	1·5	7·2	87·3	*39*	*3·1*	*7·9*	7·5	nil	*4*	*<0·1*	1000	1060
	molar { enamel . .	—	—	—	—	32·2	0·83	2·6	5·4	nil	—	—	—	170
E.621.	*Elephas* cf. *planifrons* molar, enamel . .	nil	0·1	4·3	86·5	*36*	*0·8*	*2·2*	4·5	—	*1*	—	—	—
E.622.	*Mastodon* cf. *arvernensis* molar, enamel . .	—	—	—	—	*36*	*2·3*	*6·4*	—	nil	*4*	*nil*	—	97
E.623.	*Rhinoceros* cf. *etruscus*, premolar, enamel	—	—	—	—	*24*	*2·0*	*8·3*	—	nil	*6*	*nil*	—	68
E.1383.	*Cervus* tibia . . .	—	—	—	—	*35*	*<0·1*	*<0·3*	—	nil	*1*	—	—	<1
E.1384.	Caprine molar { enamel .	0·09	0·7	7·6	—	*32*	*0·7*	*2·2*	9·4	nil	*2*	—	—	0
	Caprine molar { dentine .	—	—	—	—	*12*	*<0·05*	*<0·4*	—	—	—	—	—	—

TABLE VI.—*Analyses of bones used for comparison*

Register No.	Age and Locality	Description	N	C	H_2O	Ash	P_2O_5	F	F/P_2O_5 (× 100)	$CaCO_3$	Fe	p.p.m. eU_3O_8
			Percentages									
E.2915.	Recent; Surface, Transvaal	Ungulate limb-bone	4·0	14·0	24·5	53·3	—	—	—	5	—	—
		Second sample	*4·1*	10·3	23·2	—	25·4	0·03	0·1	5	<0·01	—
E.2912.	Neolithic dolmen, chalky soil, Coldrum, Kent	*Homo sapiens* skull	*1·9*	6·3	18·2	70·8	*23*	*0·3*	*1·3*	13	<*0·1*	1
E.2914.	Mesolithic ?, peaty clay, Branston, Notts	*Homo sapiens* rib	4·6	12·3	19·1	63·4	—	—	—	2	—	—
M.1913.	Mesolithic, sand, Tilbury, Kent	*Homo sapiens* skull	0·3	10·6	16·9	71·5	*24*	*1·1*	*4·6*	7	*0·5*	—
E.1361–2.	Upper Palaeolithic burial ?, sandy gravel, Galley Hill, Swanscombe, Kent	*Homo sapiens* limb-bones	*1·6*	7·3	13·9	75·5	28·7	0·56	2·0	4·3	1	—
E.2709.	Upper Pleistocene or Holocene loam, Halling, Kent	*Homo sapiens* limb-bone	0·03	0·5	6·9	87·4	*30·5*	*0·9*	*3·0*	13·8	*0·2*	12
M.17012.	Upper Pleistocene loam, Kingston Hill (?), Surrey	*Homo sapiens* skull	1·1	2·6	13·1	81·0	28·9	0·65	2·3	10·9	5	3
Cheddar Museum	Upper Pleistocene cave-earth, Gough's Cave, Cheddar	*Rangifer tarandus* mandible	1·5	4·4	14·6	67·5	16·3	0·14	0·9	28·2	<0·15	—
M.12946.	Upper Pleistocene sand, Lloyd's site, City of London	*Elephas primigenius* femur	0·1	2·6	10·8	81·6	*27·5*	*1·3*	*4·7*	12·7	3	—
M.12575.	Upper Pleistocene clay, Lloyd's site, City of London	*Rhinoceros antiquitatis* ulna	3·4	10·4	18·9	67·1	*26·0*	*1·1*	*4·2*	8	*2*	<1
M.15709.	Middle Pleistocene, Middle Gravels, Barnfield pit, Swanscombe, Kent	*Homo* sp. Skull (occipital)	nil	3·7	11·3	85·3	27·8	1·70	6·1	8·3	1·5	27
E.2710.	Middle Pleistocene, Middle Gravels, Barnfield pit, Swanscombe, Kent	Bovine rib	trace	1·1	7·6	88·5	*30*	*2·0*	6·7	7·2	*1*	32
M.5137.	Early Upper Pleistocene brickearth (loam), Crayford, Kent	*Rhinoceros* ulna	—	—	—	—	*28·5*	*1·0*	*3·5*	13	*0·1*	(8)*
N.H.M. Paris	Early Upper Pleistocene sands, Menchecourt, (Somme)	*Rhinoceros* astragalus	—	—	—	—	*35*	*1·2*	*3·4*	—	<*0·5*	(10)*

* Estimation on an associated bone.

TABLE VII.—*Analyses of teeth used for comparison*

Register No.	Age and Locality	Description	Percentages N	C	H_2O	Ash	P_2O_5	F	$F/P_2O_5 \times 100$	$CaCO_3$	Fe	p.p.m. eU_3O_8
Unreg.	Modern	*Pongo* canine, dentine	3·9	12·8	24·0	64·3	—	—	—	4·5	—	—
Unreg.	Modern	*Pan* molar enamel	trace	0·7	6·6	89·6	—	—	—	4·2	—	—
		dentine	3·2	—	—	—	24·7	<0·06	<0·3	7·0	<1·0	—
ZD.496A.	Modern, Canada	*Castor canadensis* molar, dentine	2·2	6·5	13·6	54·5	—	—	—	5·0	—	—
M.17016.	Upper Pleistocene loam, Kingston Hill ?, Surrey	*Homo sapiens* molar	0·3	—	—	—	—	—	—	—	—	—
Cheddar Museum	Upper Pleistocene, Gough's Cave, Cheddar	*Rangifer tarandus* molar, dentine	1·64	4·6	13·9	69·0	—	—	—	26·6	—	—
E.2916.	Lower Pleistocene, Ghar Dalam Cave, Malta	*Hippopotamus* molar, dentine	nil	nil	7·0	87·2	34·0	··0·1	0·3	13·8	<0·1	7
M.17034.	Lower Pleistocene loam, Ichkeul, Tunisia	*Elephas africanavus* (= cf. *planifrons*)										
		enamel	trace	nil	5·2	86·6	36·8	1·00	2·7	8·4	0·15	<480
		dentine	—	—	—	—	32·0	2·7	8·4	11·4	0·8	580
M.3776.	Lower Pleistocene, Red Crag (sand), Felixstowe, Suffolk	*Mastodon arvernensis* molar, enamel	—	—	—	—	33·0	1·60	4·9	—	4	38
43483.	Lower Pleistocene, Red Crag (sand), Suffolk	*Mastodon arvernensis* molar, dentine	0·07	—	—	88·2	26·9	1·89	7·0	9·3	c.9	46
E.2918.	Lower Pleistocene, Siwalik Beds	*Elephas planifrons* molar enamel	—	—	—	—	39·0	0·78	2·0	4	<0·1	45
		cementum, dentine	—	—	—	—	36·5	2·58	7·1	9	0·1	56
M.15647.	Lower Pleistocene, Bain Boulder Bed, Pakistan	*Elephas* cf. *planifrons*										
		enamel	—	—	—	—	38·1	0·54	1·4	5·8	<0·1	24
		cementum, dentine	—	—	—	—	34·8	2·55	7·3	11	0·1	

6. CHEMICAL CHANGES IN BONES: A NOTE ON THE ANALYSES[1]

By C. F. M. FRYD

Department of the Government Chemist, London

It is obvious that organic material must undergo changes of a chemical nature during the process of fossilization, and early in the last century Middleton (1844) pointed out that some at least of these changes were not complete in periods which were measurable in geological terms. Carnot (1893) examined the rate of accumulation of fluorine in bones as a measure of age. Results indicated a general trend, influenced so greatly by local variables as to be of no direct value. However, Oakley (1948) suggested that the fluorine content of bones from a limited area, as at Piltdown, or from contiguous sites, could with reservations be used to determine the contemporaneity or otherwise of fossils found in physical association; and since that date experience has accumulated (Oakley & Montagu 1949, Oakley & Hoskins 1950) on the extent to which this principle can be used. Further, this principle is of application whether the change investigated is of an additive nature – such as the incorporation of dissolved fluorine and possibly uranyl ions in the hydroxyapatite or skeletal bone – or degradative – such as the loss of fat (Gangl, 1936) or carbon and nitrogen (e.g. Cook & Heizer, 1952); or even sometimes when it is of a partly physical nature such as the accumulation within the porous structure of the bone of oxides of iron and other metals, calcium carbonate, or other salts.

In the present investigation we in the Department of the Government Chemist have endeavoured to assist in solving the Piltdown problem by determining as accurately as possible on the very small samples available the content of fluorine, phosphate and iron by adaptation of published methods, and chromium and potassium spectographically. The content of SO_4 has also been determined on one sample. In addition, carbonates have been determined by the use of an apparatus devised for the purpose (Fryd 1954); the carbonate content is of value both as measure of calcareous infiltration and consequent sealing off of originally porous material, as an indication of pH in past conditions and as a necessary subtraction from the total CO_2 obtained in the process of determining organic carbon content. Attempts have been made to determine the fat content of fossil bones by adaptation of published methods, but so far no method of value for samples of a very few milligrams in weight, such as are available from Piltdown material, has emerged. The content of

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[1] Published by permission of the Government Chemist.

organic carbon has been calculated in this laboratory from a combination of our own figures with those supplied by Drs. Weiler and Strauss of Oxford.

The water of the bone samples was determined by Drs. Weiler and Strauss in the course of their normal routine of C–H analysis, and not in accordance with the special procedure adopted by Cook & Heizer (1952) which involves preliminary drying at 90° and consequently yields lower values.

The nitrogen content of samples was determined in some cases by Mrs. A. Foster using a modification of the micro-Kjeldahl method devised by her in collaboration with Dr. J. D. H. Wiseman ; and in other cases by Drs. Weiler and Strauss using the Dumas method adapted for small samples.

It is hoped to publish full details of the experimental work carried out in the Government Laboratory elsewhere in the near future (Hoskins & Fryd, 1955).

7. THE X-RAY CRYSTALLOGRAPHY OF THE PILTDOWN FOSSILS

By G. F. CLARINGBULL AND M. H. HEY

Department of Minerals, British Museum (Natural History)

IN order to evaluate a suggested method of fluorine age determination by measurement of changes in the X-ray diffraction pattern of hydroxy-apatite with variation of fluorine content (Niggli, Overweel, & van der Vlerk, 1953) a number of bone samples of varying ages were heated to re-crystallize the apatite. One of these heated samples gave an unidentifiable diffraction pattern and was thus unsuitable for the application of the method. This sample, a drilling from the Piltdown cranium, on examination by X-ray diffraction in the unheated condition, was found to be a mixture of gypsum and apatite. A subsequent examination by the same method of many of the Piltdown specimens (see Table VIII) showed that gypsum was widely distributed in them. Large amounts were found in most specimens except tooth enamels.

With the object of accounting for this unusual occurrence of gypsum in bone, not apparently previously recorded, samples of gravel and loam were collected from the Piltdown site and were examined by chemical and X-ray diffraction methods. A sample of water from a well ¼ mile NE. of the site was also examined for sulphate. The sulphate contents of both water and soil samples, as determined by Dr. Roy C. Hoather and Dr. C. Bloomfield, are notably low.[1] Separation of fine fractions from the loam and gravel samples failed to disclose the presence of sulphate minerals and gave only diffraction patterns of clay minerals and quartz. These results tend, therefore, only to emphasize the anomalous character of the the gypsum in the bone and to rule out its introduction by natural processes. As there was no obvious reason for the intentional introduction of gypsum as such into the supposed fossils it seemed likely that it might have resulted from reaction with a solution used for colouring more recent bones to simulate iron-stained fossils.

An additional line of investigation supported this theory of chemical treatment. Part of a skull from Barcombe Mills in the C. Dawson collection at the British Museum (Nat. Hist.) had some adhering matrix. The skull fragments were found to have a composition similar to that of Piltdown, namely gypsum and apatite,

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[1] Water from the well of the " Piltdown Man " Inn, kindly analysed by Dr. Hoather in the Counties Public Health Laboratory, London, contained 63 parts per million SO_3; that from Barcombe Mills 47 parts per million. Dr. C. Bloomfield of the Rothampstead Experimental Station found the SO_3 in the fine fraction of the Piltdown gravel to be 3·9 mg. per 100 g.

TABLE VIII.—*X-ray examination of Piltdown specimens*

Geol. Dept. Reg. No.	X (Film No.)	Nature of specimen	Estimated gypsum content
E.590	6346	Piltdown Skull I, left fronto-parietal	+
E.591	6343	,, ,, I, left temporal	++
E.592	6342	,, ,, I, right parietal	++
E.593	6384	,, ,, I, occipital	+
E.593	6481	,, ,, I, additional fragment of occipital	+
E.594	6447	Piltdown Mandible, bone	
E.594	6478	,, ,, molar	
E.595	6437	*Mastodon*, molar	
E.596	6438	*Elephas* cf. *planifrons*, molar	
E.598	6368	*Hippopotamus*, molar	++
E.599	6439	,, premolar	+
E.600	6369	*Cervus elaphus*, antler	
E.601	6364	,, ,, metatarsal	
E.602	6440	*Equus*, molar	+
E.603	6448	*Castor*, molar	
E.610a	6385	Piltdown Skull I, nasal	++
E.610b	6386	,, ,, I, turbinal	++
E.611	6477	,, Canine	
E.615	6370	Worked elephant bone	
E.616	6367	Fragment of bone from base of gravel	tr.
E.617	6389	,, ,, ,, ,, ,, ,, ,,	
E.618	6441	Castor, incisor	+
E.619	6345	,, mandible	++
E.620	6442	*Elephas* cf. *planifrons*, molar	
E.622	6443	*Mastodon*, molar	
E.623	6444	*Rhinoceros*, molar	
E.644a	6387	Barcombe Mills Skull, frontal	++
E.644b	6348	,, ,, ,, parietal	+
E.644c	6494	,, ,, ,, zygoma	++
E.646	6352	Piltdown Skull II, frontal	++
E.647	6353	,, ,, II, occipital	++
E.648	6445	,, ,, II, isolated molar	
E.1383	6365	*Cervus*, tibia	

but the matrix was found to contain calcium and ammonium sulphate, although the fine fractions of freshly coloured gravel from the locality contained no appreciable sulphate and consisted of clay minerals.

The most obvious method of producing a brown iron stain on bone is by simple soaking in a solution of a suitable iron salt. Since gypsum is much more soluble in neutral solutions than is hydroxy-apatite, but is less soluble than the latter in sufficiently acid sulphate solutions, it appeared possible that a fairly acid iron sulphate solution used for staining might at the same time convert part of the bone to gypsum. On general chemical grounds, it seemed possible that there might only be a narrow range of pH within which the solution would be sufficiently acid to convert hydroxy-apatite to gypsum but not too acid to deposit iron oxide and stain the specimens. In fact the range of effective pH seems to be quite wide, at least pH 2·5 to pH 6.

Iron alum (ferric ammonium sulphate) has a distinctly acid reaction and it was expected that strong solutions might effect some conversion to gypsum. Experiments showed that even a solution as weak as 2½% was effective in this direction and at the same time produced fairly full brown colour. Ferrous sulphate and ferrous ammonium sulphate are practically neutral in reaction and would not be expected to produce gypsum so readily, but a few experiments were made with ferrous sulphate. These showed that although it had much less reactivity than iron alum some replacement of apatite by gypsum could be effected. The results of these experiments are given in Table IX; Plate 31 shows the X-ray diffraction photographs.

It seems reasonable to conclude, therefore, that the gypsum in these Piltdown specimens is the result of their treatment with solutions of an iron sulphate. In order to produce a similar replacement of the hydroxy-apatite of buried bone it would appear necessary to postulate a soil composition quite unlike that at Piltdown or indeed anywhere except perhaps in the close proximity of a sulphide ore-body undergoing active weathering.

TABLE IX.—*Artificial iron-staining of bone*

Expt. Number	Solution used	Treatment	Degree of conversion of apatite to gypsum	Colour after treatment
		WHITE BONE, SUB-FOSSIL (NEOLITHIC SKULL, COLDRUM, KENT)		
A	Saturated iron alum	36 hr. *ca.* 70°C.	Complete	Yellowish-brown
G	,, ,, ,,	6 hr. *ca.* 70°C.	Almost complete	Yellowish-brown
C	,, ,, ,,	48 hr. room temp.	Complete	Off white—unchanged
F	,, ,, ,,	12 hr. room temp.	Partial	Very pale buff, little change
L	10% iron alum	96 hr. room temp. then NH_3 vapour for 2 hours	Complete	Reddish-brown
M	5% ,, ,,	Ditto	Partial	Light brown
N	2½% ,, ,,	,,	,,	Patchy, reddish-brown
O	Saturated ferrous sulphate	24 hr. *ca.* 70°C.	,,	Variable chocolate brown
P	Ditto	40 hr. room temp.	,,	Light brown
		FRESH BONE		
2617	Saturated iron alum	9 hr. *ca.* 70°C.	,,	Pale yellow — little change

8. THE BLACK COATING ON THE PILTDOWN CANINE

By A. E. A. WERNER AND R. J. PLESTERS

Research Laboratory, National Gallery

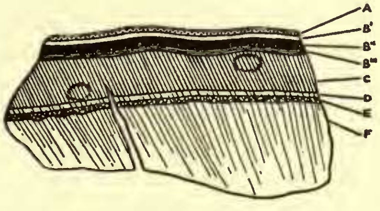
Optical examination of cross-section

In a cross-section of the black coating adhering to a fragment of the root of the canine (Text-fig. 6) the following layers can be distinguished :

(*a*) very thin scattering of a white crystalline material on the surface, thickness *c.* 0·015 mm. ; (*b*) three dark brown structureless layers (the middle one almost black) probably comprising the cementum layer of the tooth, *c.* 0·1 mm. ; (*c*) stained outer zone of the striated dentine, pale brown semi-transparent, *c.* 0·2 mm. ; (*d*) very thin zone of pale yellowish staining, *c* 0·015 mm. ; (*e*) thin zone of orange pigmentation, which shows under high power a reticulate structure, *c.* 0·02 mm. ; (*f*) white, semi-transparent dentine with characteristic oblique striation.

Chemical examination of cross-section

The zoned appearance of the cross-section suggested that some material from the black coating had been absorbed preferentially through different depths. The surface was treated with organic solvent but little or no solvent effect was noted. It was then treated with dilute hydrochloric acid and a drop of potassium ferrocyanide solution. Excess was washed off with distilled water. The top layers showed a dense mass of Prussian blue, but the pale brown zone below remained unchanged (except where the precipitate had floated into the cavities). Zone *d* was coloured a pale green. Zone *e* was dark blue and Prussian blue penetrated along the striations into the unstained dentine (*f*).



TEXT-FIG. 6. Thin-section of a fragment of the root of the Piltdown canine, showing the zones of staining. × 30 (approx.).

Chemical examination of scrapings of the black coating

Under the microscope the scrapings appeared as deep golden brown translucent lumps ; it was difficult to distinguish between pigment and medium, but a few reddish brown pigment particles were visible. The usual resin solvents—acetone, ethyl alcohol, benzene, chloroform—only extracted a small quantity of material from the sample. The thin cloudy ring of extracted material fluoresced faintly in ultra-violet light. After evaporation of the solvent, the sample itself was left as a hard intact mass. (Paint having an oil-resin medium often behaves in this way, a little of the resin being extracted by organic solvents, yet the paint film itself remaining apparently unchanged. Bituminous surface coatings also behave in a similar manner, a little transparent material being extracted by such solvents). Aqueous ammonia had a slight solvent effect, and alcoholic ammonia slightly greater. Morpholine and alcoholic sodium hydroxide softened and gradually disintegrated the sample. The golden brown transparent material remained dissolved completely in concentrated hydrochloric acid giving a yellow solution. This solution gave a copious precipitate of Prussian blue with potassium ferrocyanide, and a strong red coloration with ammonium thiocyanate. It must therefore contain ferric iron. From the appearance and solubility of the material this would seem to indicate the presence of a transparent iron-oxide pigment.

Further scrapings were heated in a small combustion tube. Heavy brownish fumes with a tarry smell were evolved, and condensed in the form of brown droplets. This suggested the presence of some bituminous material and would also be consistent with the behaviour of the scrapings to solvents. The incombustible residue dissolved in concentrated hydrochloric acid, and gave very strong positive reaction for iron (Fe^{+++}).

Conclusions

The black coating contains a considerable amount of a transparent brown iron-oxide pigment; it contains some organic matter which seems to be of a bituminous nature ; and the solubility tests do not exclude the presence of a little oil and/or resin. It therefore seems that the black coating is a paint consisting of a natural bituminous pigment, such as Cassel Earth or Cologne Earth (Vandyke brown), which contains a fairly high proportion of iron oxide, rather than a pure iron oxide pigment mixed with bitumen. The crackle pattern of the paint and its tough, non-brittle character (as examined on the tooth itself) are consistent with the above findings, and would suggest moreover that the surface coating is not of a very great age.

9. THE GEOLOGY OF THE PILTDOWN NEIGHBOURHOOD[1]

By F. H. EDMUNDS

Geological Survey of Great Britain

THE geology of the Piltdown neighbourhood was described by Charles Dawson in the introduction to his joint paper with Smith Woodward on the Piltdown Skull (1913 : 117). No geological survey of the superficial deposits of the area had then been published. In 1925 the writer, in the course of his official work on the Geological Survey of Great Britain, mapped the superficial deposits of a large area around Lewes on the scale of 6 in. to the mile. The spread of gravel which according to Dawson yielded the Piltdown Skull and other fossils was included in this area.

The Piltdown gravel spread rests on the Tunbridge Wells Sand formation. It measures but 75 yd. × 270 yd. and is one of a number of fragments of a well-defined but much dissected and denuded river terrace which borders the River Ouse. This terrace constantly maintains a height of about 50 ft. above the river, and the Piltdown spread itself is no exception. The 100-ft. contour of the 6-in. Ordnance Survey maps, Sussex 40 NW. and NE. (1911 and later editions), actually crosses the gravel spread, while the 50-ft. contour almost touches the River Ouse at Gold Bridge, the nearest point of the river. This is shown on the accompanying sketch-map.

The obvious correlation is with the 50-ft. terraces of the Thames and other English rivers ; that is, the gravel is of Upper Pleistocene age.

In 1925 there were some two feet of brickearth lying on an equivalent thickness of gravel, which rested on Tunbridge Wells Sand. The gravel was seen to be light brown to orange-red in colour, and to consist largely of sand, with small waterborne pieces of ferruginous sandstone and ochreous flints. Many of the flints were pitted with round or pentangular spaces. The brickearth appears to be water deposited, and to be only slightly later in age than the gravel. It may or may not be contemporaneous with extensive brickearth deposits of Upper Pleistocene age in Kent, some of which have been equated with the loess of Europe. It is of insufficient importance for separate distinction on the Geological Survey map.

Not unexpectedly the detailed survey of 1925 differs in certain particulars from Dawson's account of 1913. This is particularly the case in the matter of height of the gravel spread above the river. Dawson estimated this at about 80 ft. Unfortunately, Sollas (1924 : 183) accepted Dawson's figure without question and equated the terrace with those at about 100 ft. (or 30 metres) above other rivers of Great Britain and Europe. Previous attention has been drawn to this false correlation (Edmunds, 1950).

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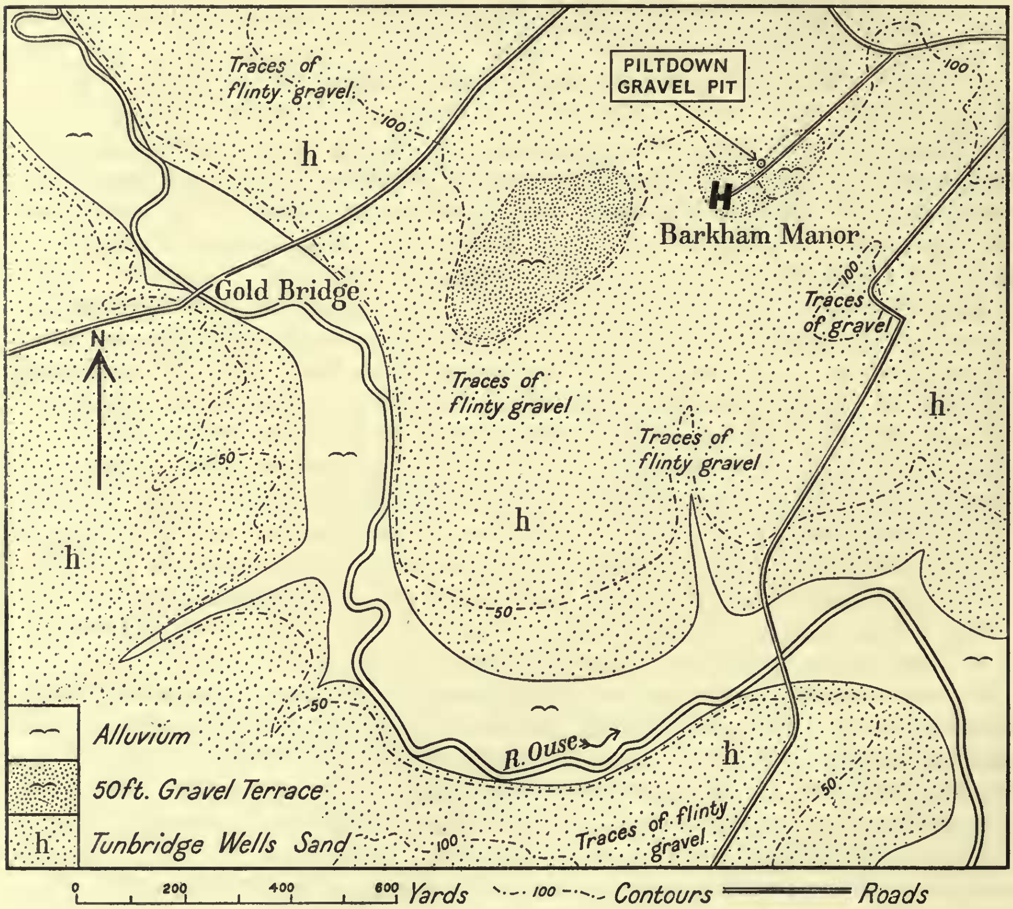
[1] Communicated by permission of the Director, Geological Survey and Museum.

The Geological Survey memoir on the Lewes district (White 1926 : 63) repeats Dawson's estimate in the text. The present writer contributed a text-figure to this memoir (White 1926, fig. 10) indicating the true elevation of the terrace. The significance of this diagram, however, does not seem to have been fully appreciated by Osborne White and the memoir shows a discordance between the text and the diagram.



Text-fig. 7. Geological sketch map of the Piltdown district.

In his 1913 account, Dawson records that the gravel occurred a few inches beneath the surface of the soil, and varied in thickness from 3 to 5 ft. In a supplementary paper (Dawson & Woodward 1914 : 82) he elaborates his description of the gravel section, to say that beneath the surface soil there occurs a bed of undisturbed gravel, from a few inches to 3 ft. in thickness which (he records) overlies a third bed, which though not always present, is well marked, and consists of pieces of ironstone and deeply patinated and iron-stained flints.

The supplementary paper also contains a furthur version of the section in the form of a drawing annotated as follows :

1. Surface soil, with occasional iron-stained subangular flints . . . Thickness = 1 foot.
2. Pale-yellow sandy loam, with small lenticular patches of dark ironstone gravel and iron-stained subangular flints . . . Thickness = 2 feet 6 inches.
3. Dark-brown ferruginous gravel, with subangular flints and tabular ironstone floor covered with depressions. 18 inches.
4. Pale-yellow finely-divided clay and sand, forming a mud reconstructed from the underlying strata. Certain subangular flints occur, bigger than those of the overlying beds. Thickness, 8 inches.
5. Undisturbed strata of the Tunbridge Wells Sand (Hastings Beds, Wealden).

(The indicated omissions from the above annotations concern fossils and flint implements).

This latter description accords reasonably well with the writer's observations made in 1925, and with a photograph of the section in Dawson's 1913 paper which shows what is obviously brickearth, about 2 ft. thick, overlying a similar thickness of gravel.

Traces of the 50 ft. terrace, in the form of *remanié* flints and sandstone in the surface soil are visible over much of the countryside bordering the River Ouse. They have not been noted above the general level of this terrace.

No great significance is to be attached to the mere presence of flints within the Weald. Dark-stained flints occur at many localities and on present-day views of the denudation of the Weald their presence is to be expected. Flints occur, however, in greater numbers in the Piltdown area than have been noted in other districts on the outcrops of the Weald Clay and earlier formations.

It is reasonable to assume that some older drift deposits may have formerly existed at higher levels in the Piltdown district. During Pleistocene times, however, denudation had been so extensive that no field evidence of any earlier drifts remains. The possible former presence above the 50-ft. terrace level of a local drift of any age can only be hypothetical.

10. THE RADIOACTIVITY OF THE PILTDOWN FOSSILS[1]

By S. H. U. BOWIE AND C. F. DAVIDSON

Atomic Energy Division, Geological Survey of Great Britain

DURING recent investigations into the geochemical distribution of the radioactive elements, it was demonstrated by the Atomic Energy Division of the Geological Survey that fossil bones, teeth and other phosphatic materials tend to accrete uranium by adsorption from percolating groundwaters (Davidson & Atkin, 1953). There is some evidence that the radioactivity of a fossil bone is dependent upon the geological age of the fossil, upon the permeability of the formation in which it is found, and upon the uranium content of the percolating waters throughout the ages. In favourable circumstances the determination of radioactivity should therefore provide a means of distinguishing older, derived fossils from contemporary bones when vertebrate remains of more then one age are found in the same geological environment. No intensive research on this topic has yet been undertaken since such academic studies are rather far removed from the Atomic Energy Division's primary function of finding workable uranium deposits.

The build-up of radioactivity in older bones is due to two separate and unrelated causes—firstly, to the longer time that these fossils have had to adsorb uranium from circulating waters and, secondly, to the increase in radioactivity as this uranium approaches secular equilibrium with its daughter elements. The adsorbed uranium has at first only about one-third of the beta radioactivity of uranium in equilibrium with its daughter elements, and the content of the latter disintegration products does not reach a maximum until equilibrium is reached—i.e. until the amount of each transitory daughter element newly generated in a given time is equal to the amount lost by decay. If uranium were present in the bone in a known amount when it was buried, and were not added to or leached away throughout its later history, the radioactivity would gradually increase for a period of several hundred thousand years, and the absolute age could be deduced therefrom. Since, however, the uranium slowly accretes after burial the radioactivity measurements can be no more than a relative indication of age between different bones found in the same geological environment.

When *The Solution of the Piltdown Problem* was published we suggested to the Keeper of Geology that radioactivity measurements might yield additional information on the relative ages of the fossils. He thereupon made a large number of bones and teeth available for radiometric assays, the results of which are reported in this note.

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[1] Communicated by permission of the Director, Geological Survey and Museum.

The study of phosphatic materials by autoradiographic techniques (Bowie, 1951) has shown that in radioactive bones, teeth and apatite crystals the radioactivity may be concentrated towards the surface of the specimen if the latter is relatively impermeable, but if the material is porous the adsorbed uranium tends to become evenly distributed throughout. Both for this reason, and because of the high sensitivity intrinsic to the method, the radiometric analyses of the Piltdown specimens have been conducted by measurement of the beta radiation emitted from the surface of the bone, this radiation emanating from a layer about 5 mm. in thickness. The technique employs a sensitive beta counter, with a thin mica end-window placed at a fixed distance (1 cm.) from the fossil under study, the assemblage being contained in a lead chamber to reduce extraneous radiation to a minimum, and connected to a scaling unit. One great advantage of the method is that it does not consume any of the fossil material, which is preserved unchanged. A disadvantage, with the equipment at present available to us, is that the specimens must be small enough (less than six inches in length) to permit their introduction into the lead chamber, and large enough (about a half-inch minimum diameter) to cover the sensitive area of the end-window counter.

Because of the variation in background count due mainly to fluctuations in cosmic radiation, the accuracy of the measurements (which is a function of the total counts recorded) depends upon the length of time allowed for the determinations. The radioactivity of a relatively uranium-rich bone can be determined with reasonable precision in a few minutes, but specimens in which the radioactivity is very feeble demand an investigation lasting one or two days. In the table below a " standard error " is given, this being a statistical expression of the standard deviation of the background count relative to the count given by the specimen plus background. It will be observed that in certain instances the standard error exceeds the count rate, the relevant specimens being devoid of any radioactivity determinable under these experimental conditions.

From the net count per minute given by each specimen, by extrapolation from analysed standards, the radioactivity has been expressed as equivalent urania (*e*.U_3O_8). This is a measurement of the true (chemical) uranium content only if the radioactive elements are in secular equilibrium and if no radioactive elements other than those of the uranium series are present. In all such phosphatic materials hitherto analysed chemically, no elements of the thorium series have been found in significant amounts ; but in the Piltdown specimens which have reputedly been treated with potassium chromate, part or all of the radioactivity may be due to the potassium isotope K^{40} if the potash salts have not been thoroughly washed out from the bone structure. One per cent. K_2O has a beta radioactivity equivalent to about 0·0007% U_3O_8.

Since we have no personal knowledge of the history or provenance of the Piltdown and other specimens submitted to us, it is not appropriate that we should attempt to interpret the results of these tests. There is a strong suggestion that the radioactivity of the bones varies sympathetically with the fluorine content, particulars of which have already been published by Oakley ; but since in relatively young fossil bones the adsorbed uranium cannot have reached secular equilibrium, for such materials radioactive measurements may be less satisfactory than fluorine determinations as pointers to age. Possibly, however, radiometric assays may be of greater value than fluorine determinations for older fossils. It should be noted that the dentine and cementum of teeth is nearly always more radioactive than the enamel (Pl. 30, fig. 13).

The analyses which we have obtained on a group of late Tertiary and Quaternary bones, listed below, suggest a rough correlation of radioactivity with age. Although there are too many variables governing the adsorption of uranium into such materials for radioactivity measurements in themselves to form a reliable means of dating the fossils, radiometric determinations seem likely to provide the palaeontologist with information which, considered in conjunction with other evidence, may be an important help in discerning the relative age of two or more groups of vertebrate remains found in the same geological environment.

TABLE X.—*Radiometric assays of Piltdown specimens*

Register No.	Locality	Description	Net counts per minute	Standard error	Per cent. eU_3O_8
E.620	Piltdown	*Elephas* cf. *planifrons* molar, cementum	354·5	±6.0	0·106
		enamel	57·5	±1·2	0·017
E.596	,,	*Elephas* cf. *planifrons* molar—			
		cementum	203·3	±3·2	0·061
		cementum and enamel	197·2	±3·1	0·059
		enamel	172·6	±2·3	0·052
E.597	,,	*Elephas* cf. *planifrons* molar, cementum	175·2	±2·6	0·053
		enamel	72·8	±2·4	0·022
E.622	,,	*Mastodon* cf. *arvernensis* molar, enamel	32·4	±0·6	0·0097
E.623	,,	*Rhinoceros* cf. *etruscus* premolar, enamel	22·8	±0·6	0·0068
E.595	,,	*Mastodon* cf. *arvernensis* molar, enamel	3·62	±0·32	0·0011
E.600	,,	*Cervus elaphus* antler	3·57	±0·35	0·0011
E.615	,,	*Elephas* femur (worked)	3·50	±0·32	0·0010
E.617	,,	Bone in clay matrix, " from base of Piltdown Gravel "	3·05	±0·14	0·0009
*E.604	,,	*Castor* molar in gravel matrix	2·50	±0·27	0·0007
E.601	,,	Cervid metatarsal	2·07	±0·32	0·0006
E.599	,,	*Hippopotamus* premolar, dentine and enamel	1·79	±0·41	0·0005
E.598	,,	*Hippopotamus* molar, dentine	1·10	±0·37	0·0003
		enamel	−0·11	±0·33	<0·0001
E.590	,,	*Eoanthropus I*, left fronto-parietal	0·91	±0·11	0·0003
E.593	Piltdown	*Eoanthropus* I occipital	0·76	±0·10	0·0002
E.644b	Barcombe Mills	*Homo* parietal fragment	0·69	±0·13	0·0002
E.591	Piltdown	*Eoanthropus* temporal	0·42	±0·11	0·0001
E.644a	Barcombe Mills	*Homo* frontal	0·34	±0·12	0·0001
*E.603	Piltdown	*Castor* molar, enamel	0·30	±0·29	<0·0001
E.1383	,,	*Cervus* tibia	0·25	±0·29	<0·0001
E.619	,,	*Castor* mandible	0·20	±0·26	<0·0001
E.592	,,	*Eoanthropus* I right parietal	0·14	±0·12	<0·0001
E.594	,,	*Eoanthropus* I mandibular ramus	0·05	±0·11	<0·0001
*E.610a	,,	*Eoanthropus* I nasals	0·03	±0·11	<0·0001
E.646	,,	*Eoanthropus* II frontal	0·02	±0·13	<0·0001
*E.618	,,	*Castor* incisor enamel	−0·05	±0·38	<0·0001
E.647	,,	*Eoanthropus* II occipital	−0·14	±0·14	<0·0001
E.1384	,,	Caprine molar, enamel	−0·21	±0·28	<0·0001
E.602	,,	*Equus* molar, mainly enamel	−0·25	±0·38	<0·0001

* Specimens either too small to cover area of end window of counter or not thick enough to be considered deep sources of beta activity. The relative values for these may be up to 50% higher than quoted.

TABLE XI.—*Radiometric assays of various Tertiary, Pleistocene and Holocene Fossils*

Register No.	Locality and age of stratum	Description	Net counts per minute	Standard error	Per cent. eU_3O_8
M.17034	Ichkeul, Tunisia, Lower Pleistocene (Lower Villafranchian)	*Archidiskodon africanavus* (=*Elephas* cf. *planifrons*)			
		molar, cementum	194·9	±1·2	0·058
		cementum and enamel	175·0	±1·1	0·052
		cementum, dentine and enamel	158·6	±1·1	0·048
33189	Touraine, Miocene	*Mastodon* molar, enamel	114·5	±2·5	0·034
15785	Siwalik Hills, "Lower Pliocene"	Ruminant molar { mainly dentine	86·8	±3·1	0·026
		Ruminant molar { enamel	49·1	±1·3	0·015
32543	Touraine, Miocene	*Mastodon* molar, enamel	50·9	±1·3	0·015
M.10436	Portslade, Brighton, Pleistocene	*Ursus* cf. *arvernensis* molar—			
		dentine and enamel	27·51	±0·49	0·0082
		enamel	3·69	±0·35	0·0011
28804	Val d'Arno, Lower Pleistocene	*Rhinoceros etruscus* molar—			
		osteodentine	26·0	±0·6	0·0078
		enamel	7·06	±0·56	0·0021
Buxton Museum	Doveholes, Derbyshire, Lower Pleistocene fissure deposit	*Mastodon* cf. *arvernensis* molar—			
		dentine	25·15	±0·37	0·0075
		enamel	3·85	±0·36	0·0012
M.11514	Herbolzheim, Baden, Upper Pliocene fissure deposit	*Mastodon arvernensis* molar—			
		dentine	22·0	±0·6	0·0066
		enamel	6·86	±0·36	0·0021
E.2918	Siwalik Hills, Lower Pleistocene	*Elephas planifrons* molar—			
		dentine or cementum and enamel	18·70	±0·6	0·0056
		enamel	14·89	±0·50	0·0045
E.2691	Ain Boucherit, Algeria, Lower Pleistocene (Lower Villafranchian)	*Archidiskodon africanavus* (= *Elephas* cf. *planifrons*) molar, dentine	18·06	±0·52	0·0054
43483	Suffolk, Red Crag, Lower Pleistocene	*Mastodon* cf. *arvernensis* molar			
		mainly dentine	15·44	±0·45	0·0046
		mainly enamel	4·44	±0·40	0·0013
M.14959	Senèze (Haute-Loire), Lower Pleistocene	*Equus robustus* premolar, dentine and enamel	15·40	±0·49	0·0046
E.2706	Dovercourt, Essex, Red Crag, Lower Pleistocene	Rolled fragment, compact bone	15·38	±0·42	0·0046

Register No.	Locality and age of stratum	Description	Net counts per minute	Standard error	Per cent eU_3O_8
M.17033	Ain Hanech, Algeria, Lower Pleistocene (Upper Villafranchian)	*Elephas* cf. *meridionalis* molar—cementum and enamel	15·07	±0·30	0·0045
E.2707	Swanscombe, Lower Gravel, Middle Pleistocene	Ungulate limb-bone	13·90	±0·51	0·0042
G.S.M. 3340	Suffolk, Red Crag, Lower Pleistocene	*Mastodon arvernensis* molar—dentine	13·05	±0·43	0·0039
		enamel	4·15	±0·13	0·0012
G.S.M. 6838	Suffolk, Red Crag, Lower Pleistocene	*Mastodon* molar mainly dentine	12·84	±0·25	0·0038
		enamel	6·77	±0·32	0·0020
M.3776	Suffolk, Red Crag, Lower Pleistocene	*Mastodon* cf. *arvernensis* molar, mainly enamel	12·72	±0·38	0·0038
93223	Ilford, Brickearth, Upper or Middle Pleistocene	*Elephas primigenius* right astragalus	10·90	±0·50	0·0033
E.2710	Swanscombe, Middle Gravels, Middle Pleistocene	Bovine rib	10·80	±0·16	0·0032
M.15709	Swanscombe, Middle Gravels, Middle Pleistocene	*Homo* occipital	9·03	±0·13	0·0027
York Museum 1/10-1-74	Trimley, Suffolk, Red Crag, Lower Pleistocene	*Elephas* cf. *planifrons* molar, cementum, dentine and enamel	8·87	±0·14	0·0027
M.15647	Bain Boulder Bed, India, Lower Pleistocene	*Elephas* cf. *planifrons* molar, cementum and enamel	7·86	±0·42	0·0024
York Museum 1a/10-1-74	Trimley, Suffolk, Red Crag, Lower Pleistocene	*Elephas* cf. *planifrons* molar, mainly enamel with some dentine or cementum	5·87	±0·33	0·0018
G.S.M. 93224	W. Wittering, "Holocene" (Pleistocene ?)	Bovid phalange	5·70	±0·30	0·0017
E.2709	Swanscombe (Ebbsfleet), Upper Pleistocene	Ungulate limb-bone	4·93	±0·28	0·0015
E.2705	Chagny-Bellecroix (Saône-et-Loire), Lower Pleistocene	*Elephas* cf. *planifrons*, fragments of dentine	4·78	±0·44	0·0014
G.S.M. C.43	Ilford, Brickearth, Middle or Upper Pleistocene	*Elephas antiquus* molar, dentine, cementum and enamel	4·17	±0·35	0·0013

TABLE XI.—*Radiometric assays of various Tertiary, Pleistocene and Holocene Fossils*—(Contd.)

Register No.	Locality and age of stratum	Description	Net counts per minute	Standard error	Per cent. eU_3O_8
E.2709	Halling, Upper Pleistocene ?	*Homo* limb-bone	4·03	±0·30	0·0012
G.S.M. 5548	Great Yeldham, Essex, Middle Pleistocene	*Bos primigenius* molar—			
		enamel	3·13	±0·39	0·0009
		enamel and dentine	2·97	±0·31	0·0009
G.S.M. 3063	Crayford, Brickearth, Upper Pleistocene	*Elephas* cf. *primigenius* metatarsal	2·77	±0·31	0·0008
G.S.M. 10284	Clapham, Bedford, Upper Pleistocene	*Elephas primigenius* molar, mainly enamel	2·60	±0·18	0·0008
E.2916	Ghar Dalam Cave, Malta, Lower Pleistocene	*Hippopotamus* molar—			
		enamel and dentine	2·41	±0·41	0·0007
		enamel	1·75	±0·30	0·0005
Brighton Museum G.6480	Portslade, Upper Pleistocene	*Elephas primigenius* molar—			
		cementum	2·21	±0·24	0·0006
		enamel	−0·15	±0·22	<0·0001
40838	Urals, U.S.S.R., Lower Pleistocene	*Elephas meridionalis* molar, cementum or dentine	1·67	±0·41	0·0005
Zieriksee Museum	Scheldt Estuary, Lower Pleistocene	*Elephas* cf. *planifrons* molar, mainly enamel	0·41	±0·12	0·0001
G.S.M. 93225	Hastings, kitchen midden	*Cervus elaphus* astragalus	0·23	±0·30	0·0001
ZD.1938	Terra del Fuego, Modern	*Homo sapiens* parietal	0·07	±0·12	<0·0001
*M.12575	Lloyd's site, London, Upper Pleistocene	*Rhinoceros antiquitatis* ulna	0·03	±0·28	<0·0001
G.S.M. 5081	Twickenham, Thames Gravel, Holocene	*Sus scrofa* mandible	−0·29	±0·45	<0·0001
G.S.M. G.S.405	Hythe, Kent, Holocene	*Sus scrofa* mandible	−0·60	±0·42	0·0001
G.S.M. 5086	Twickenham, Thames Gravel, Holocene	*Capreolus capreolus* innominate	−0·68	±0·45	<0.0001
—	Kent, Modern	*Meles meles* frontal	−0·92	±0·28	<0·0001

* See footnote to Table X.

II. THE FLUORIMETRIC DETERMINATION OF URANIUM IN THE PILTDOWN FOSSILS[1]

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IN 1950 Dr. K. P. Oakley asked Dr. C. R. Hoskins of the Department of the Government Chemist to investigate the estimation of uranium in fossil bones, for use as a dating element to supplement the fluorine method.[2]

Dr. Hoskins' preliminary work showed that chemical methods were not sufficiently sensitive for the extremely small samples available, and that a sensitive fluorimeter was necessary. The Chemical Research Laboratory had developed two methods for the isolation of uranium (see *Chemical Methods for the Detection of Uranium*, Stationery Office, London, 1950 ; and U.S. Geol. Surv. Circular No. 199). One, involving chromatographic separation on a cellulose powder column was found to be useless for the samples being examined. The other, using solvent extraction into ethyl acetate, seemed to be adaptable to the estimation of uranium in small samples, and Mr. R. A. Wells of the Chemical Research Laboratory kindly gave instruction in the technique used.

The method finally adopted was as follows :

A sample of bone (2 to 10 mg.) was weighed into a Pyrex tube (13 cm. × 0·75 cm. I.D., with a B.10 stopper) and refluxed with 0·2 ml. of conc. nitric acid until solution appeared to be complete. After cooling, saturated aluminium nitrate (0·5 ml. of a solution in 1% nitric acid), 0·5 ml. of water and 1·5 ml. of carefully purified ethyl acetate were added. The mixture was shaken and after settling, 1·0 ml. of the ethyl acetate was pipetted on to 0·7 gm. of sodium fluoride. The solvent was evaporated, the sodium fluoride dried under infra-red lamps, and finally fused. The amount of uranium was measured in the fluorimeter.

Factors limiting the accuracy of the results were :

(1) Weighing was to the nearest 0·1 mg. only.

(2) The conversion factor from scale reading to uranium content was empirical.

(3) The lowest readings did not differ enough from the background readings to admit of satisfactory determination.

(4) Fluctuation in the meter readings allowed only estimation of the second significant figure.

(5) The carry over of the multiranger was not accurate at the ends of the scale, and errors of 20% could occur.

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[1] Published by permission of the Government Chemist.

[2] The request was inspired by information received from Dr. C. F. Davidson and Professor Harrison Brown. K.P.O.

Taking these factors into consideration only one significant figure can be given for the uranium percentage.

The uranium adsorbed in bone has been shown by Davidson & Atkin (1953) to be concentrated in the surface layers and along cracks and crevices, not necessarily uniformly over any area. A "fair sample" of the bone for analysis must, then, have a representative proportion of the outer layer to the inner material, if valid deductions as to the uranium content of the bone as a whole are to be drawn from the analysis of a single powdered sample.

The results are of value in the following respect : The radioactivity of the Piltdown fossils could have been due either to uranium or to potassium of isotopic mass 40, and it can be shown that 1% of K_2O is equal in β particle activity to 0·0007% = 7 p.p.m. of uranium. The results obtained are accurate enough to show that the radiometric assays of Bowie & Davidson give a reliable figure for the uranium content of the samples examined, though difficulties in sampling, arising from differences in uranium adsorption with different bone or tooth structures, necessitate very careful interpretation of the results if the correct proportion of uranium in the bone as a whole is to be estimated.

TABLE XII.—*Uranium content of Piltdown and other fossils.*

Reg. No.	Description	% U_3O_8	U_3O_8 p.p.m.
E.590	Piltdown I, left parietal	0·0004	4
E.591	,, I, left temporal	0·0004	4
E.592	,, I, right parietal	0·0002	2
E.593	,, I, occipital	0·0008	8
E.594	,, mandible	<0·00002	<0·2
E.596	,, *Elephas* cf. *planifrons* molar	0·1	1000
E.597	,, *Elephas* cf. *planifrons* molar, cementum	0·1	1000
E.620	,, *Elephas* cf. *planifrons* molar, cementum	0·1	1000
E.622	,, *Mastodon* molar	0·002	20
M.15709	Swanscombe skull, occipital	0·003	30
M.17034	Ichkeul "*Elephas* cf. *planifrons*" molar, dentine	0·02	200

I acknowledge, with much pleasure, the loan of a fluorimeter by the Atomic Energy Research Establishment, Harwell, and the help given by Mr. R. A. Wells of the Chemical Research Laboratory.

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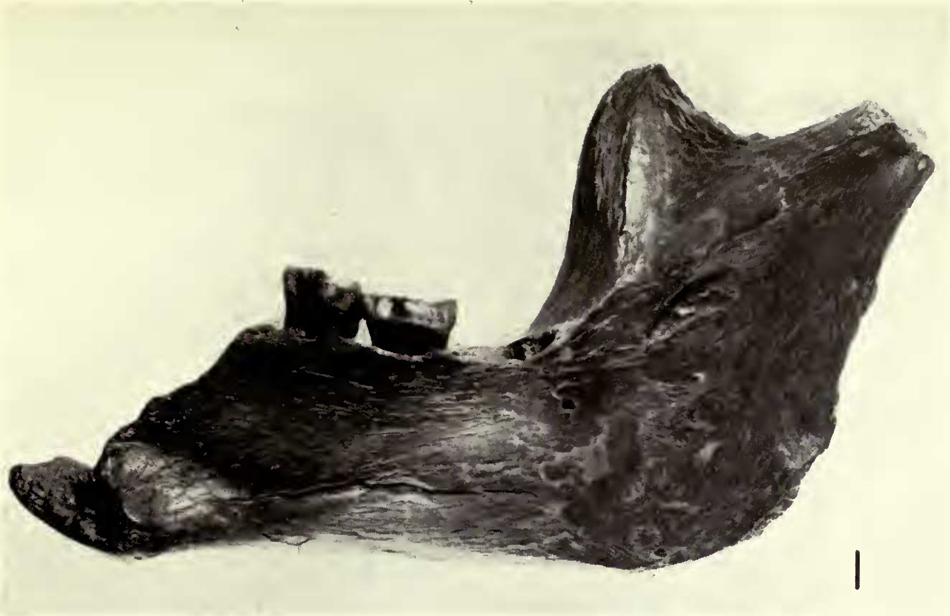
EXPLANATION OF PLATES

PLATE 27

Photograph of the medial aspect of (Fig. 1) the Piltdown mandible compared with (Fig. 2) a female orang mandible (unstained) which has been broken in the same manner as the " fossil " specimen, and in which the first and second molar teeth have been planed down to a corresponding level of dentine exposure. It should be noted that in the Piltdown mandible the angle has been slightly reduced by abrasion, and the lower margin of the mandibular foramen has been broken.

[*Photographs:* Fig. 1 by *C. Horton,* Fig. 2 by *F. Blackwell.*]



1

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PLATE 28

FIG. 3. (A–C) "Palaeolithic flint implements" recorded from the Piltdown gravel (left to right E.607, 605, 606) and (D) "Morris's" flint core (E.2690), all showing areas of intense localised battering. Note that where a chip (arrow) has been removed from E.606 the cortex is pure white below the superficial stain. × 2/3.

FIG. 4. The iron-stained surface of flint E.607 (A above). The speckly character of the stain is typical of artificial pigmentation of patinated flint. × 2.

FIGS. 5–6. Flaked surface of flint E.607 (Fig. 5) compared with the naturally iron-stained surface of a flint (E.965) from the Piltdown gravel (Fig. 6). The ink circles indicate areas which were wiped immediately after dilute hydrochloric acid had been applied to them. The stain on E.607 was removed, the natural stain on E.965 was unaffected. Natural size.

[*Photographs: C. Horton.*]

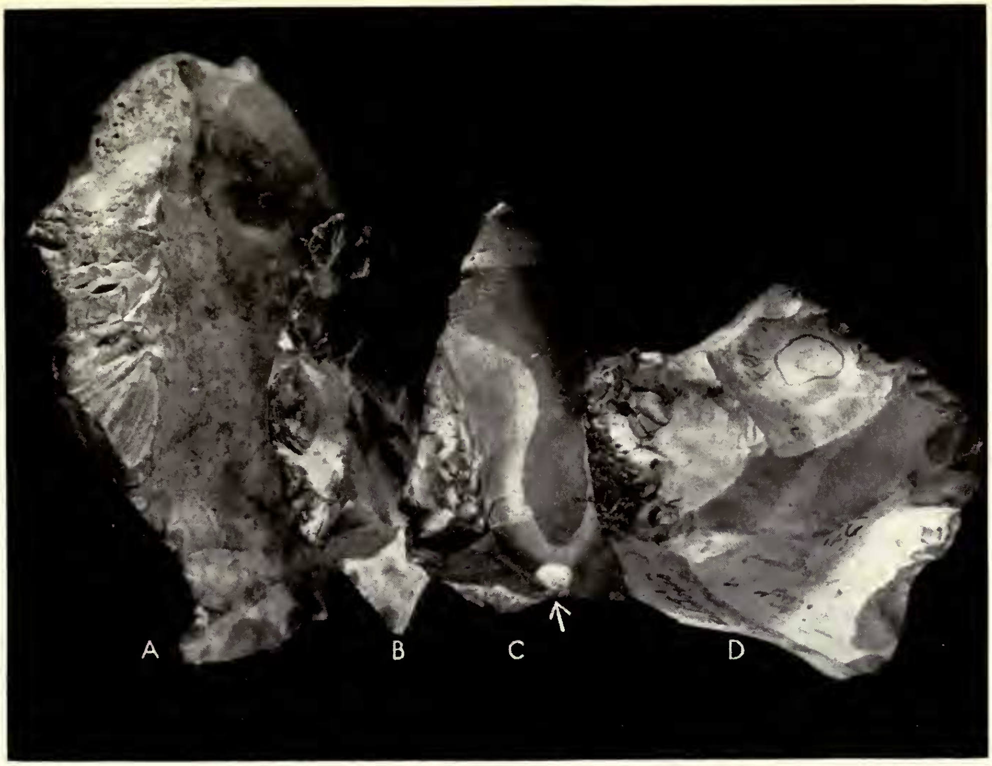

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PLATE 29

Figs. 7, 8. The pointed end of the Piltdown bone " implement ", showing details of the cuts on the lateral faces. E.615. Natural size.

Fig. 9. The cut facets at the rounded butt end of the " implement ". Natural size.

Fig. 10. A piece of fossil bone from the Swanscombe gravels which has been shaped with a steel razor and artificially iron-stained ; it reproduces all the essential features of the Piltdown bone " implement ". E.2707. × 2/3.

[*Photographs : C. Horton*].

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PLATE 30

Fig. 11. Electron-micrograph of decalcified residue of a sample of the Piltdown mandible, showing banded collagen fibres. × 30,000 (approx.)

Fig. 12. Section of fragment of molar tooth of *Elephas* cf. *planifrons* in the Piltdown collection (E.620). × 2.

Fig. 13. Autoradiograph (intensified) of the same section, produced by six weeks contact with very sensitive film (Ilford nuclear research pl., emulsion type B.2); demonstrating the high radioactivity of the dentine and cementum layers. × 2.

[*Photographs:* Fig. 11 by *A. V. W. Martin*, Fig. 12 by *C. Horton*, Fig. 13 by *S. H. U. Bowie.*]

11

12

13

PLATE 31

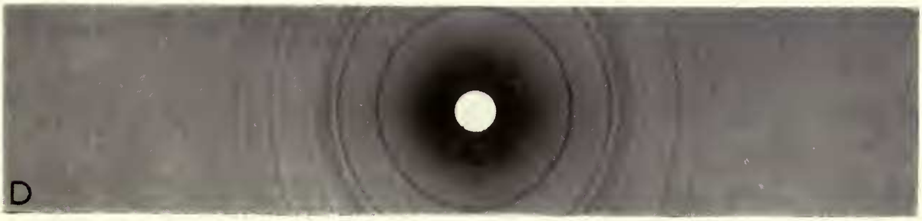
X-ray diffraction photographs on 6 cm. diameter camera ; Co-Kα radiation. A. Gypsum (Mosul marble). B. Apatite (Jumilla, Spain). C. Apatite (Fragment of bone). D. Gypsum + apatite (Piltdown skull, frontal). E. Gypsum (Neolithic skull bone from Coldrum, Kent, soaked for 96 hours in 10% solution of iron alum).

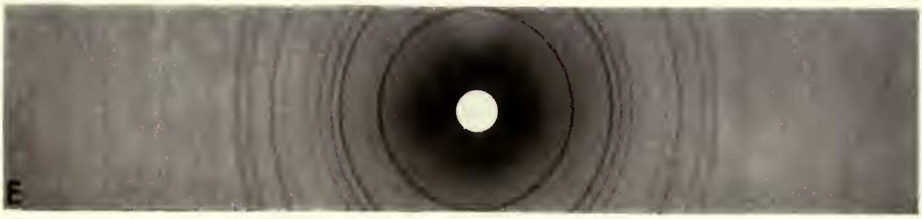
[*Photographs taken in the Department of Minerals.*]


A


B


C


D


E